

Chapter 7

Choosing Among MHC Technologies

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) organizes data collected or developed throughout the assessment of the baseline non-conveyorized electroless copper process and alternatives in a manner that facilitates decision-making. First, risk, competitiveness, and conservation data are summarized in Section 7.1. This information is used in Section 7.2 to assess the net benefits and costs to society of implementing an alternative as compared to the baseline. Section 7.3 provides summary profiles for the baseline and alternatives.

Information is presented for eight technologies for performing the making holes conductive (MHC) function. These technologies are electroless copper, carbon, conductive ink, conductive polymer, graphite, non-formaldehyde electroless copper, organic-palladium, and tin-palladium. All of these technologies are wet chemistry processes, except the conductive ink technology, which is a screen printing technology.¹ The wet chemistry processes can be operated using vertical, immersion-type, non-conveyorized equipment or horizontal, conveyorized equipment.² Table 7.1 presents the processes (alternatives and equipment configurations) evaluated in the CTSA.

Table 7.1 MHC Processes Evaluated in the CTSA^a

MHC Technology	Equipment Configuration	
	Non-Conveyorized	Conveyorized
Electroless Copper (BASELINE)	✓	✓
Carbon		✓
Conductive Polymer		✓
Graphite		✓
Non-Formaldehyde Electroless Copper	✓	
Organic-Palladium	✓	✓
Tin-Palladium	✓	✓

^a The human health and aquatic toxicity hazards and chemical safety hazards of the *conductive ink technology* were also evaluated, but risk was not characterized.

¹ Only limited analyses were performed on the conductive ink technology for two reasons: 1) the process is not applicable to multi-layer boards, which were the focus of the CTSA; and 2) sufficient data were not available to characterize the risk, cost, and energy and natural resources consumption of all of the relevant process steps (e.g., preparation of the screen for printing, the screen printing process itself, and screen reclamation).

² Conveyorized MHC equipment is a relatively new innovation in the industry, and is usually more efficient than non-conveyorized equipment. Many of the newer technologies are only being used with conveyorized equipment, while most facilities in the U.S. still use a non-conveyorized electroless copper process to perform the MHC function.

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

The results of the CTSA suggest that the alternatives not only have environmental and economic benefits compared to the non-conveyorized electroless copper process, but also perform the MHC function as well as the baseline. While there appears to be enough information to show that a switch away from traditional electroless copper processes has reduced risk benefits, there is not enough information to compare the alternatives to this process among themselves for all their environmental and health consequences. This is due to a lack of proprietary chemical data from some suppliers³ and because toxicity values are not available for some chemicals. In addition, it is important to note that there are additional factors beyond those assessed in this CTSA which individual businesses may consider when choosing among alternatives. None of these sections make value judgements or recommend specific alternatives. The actual decision of whether or not to implement an alternative is made outside of the CTSA process.

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

Earlier sections of the CTSA evaluated the risk, performance, cost, and resource requirements of the baseline MHC technology as well as the alternatives. This section summarizes the findings associated with the analysis of MHC technologies. Relevant data include the following:

- Risk information: occupational health risks, public health risks, ecological hazards, and process safety concerns.
- Competitiveness information: technology performance, cost and regulatory status, and international information.
- Conservation information: energy and natural resource use.

Sections 7.1.1 through 7.1.3 present risk, competitiveness, and conservation summaries, respectively.

7.1.1 Risk Summary

This risk characterization uses a health-hazard based framework and a model (generic) facility approach to compare the health risks of one MHC process technology to the health risks associated with switching to an alternative technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including printed wiring board (PWB) shops in the U.S. and abroad, supplier data, and input

³ Electrochemicals, LeaRonal, and Solution Technology Systems provided information on proprietary chemical ingredients to the project. Atotech provided information on one proprietary ingredient. W.R. Grace was preparing to provide proprietary information on chemical ingredients in the conductive ink technology when it was determined that this information was no longer necessary because risk from the conductive ink technology could not be characterized. The other suppliers participating in the project (Enthone-OMI, MacDermid, and Shipley) declined to provide proprietary information.

from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors.

When using the results of the risk characterization to compare health effects among alternatives, it is important to remember that it is a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. It should also be noted that this approach does not result in any absolute estimates or measurements of risk, and even for comparative purposes there are several important uncertainties associated with this assessment (see Section 3.4).

The exposure assessment for the risk characterization used, whenever possible, a combination of central tendency and high-end assumptions (i.e., 90 percent of actual values are expected to be less) to yield an overall high-end exposure estimate. Some values used in the exposure calculations, however, are better characterized as “what-if,”⁴ especially pertaining to bath concentrations, use of gloves, and process area ventilation rates for a model facility. Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a “what-if” descriptor, the entire assessment should be considered “what-if.”

As with any risk characterization, there are a number of uncertainties involved in the measurement and selection of hazard data, and in the data, models, and scenarios used in the exposure assessment. Uncertainties arise both from factors common to all risk characterizations (e.g., extrapolation of hazard data from animals to humans, extrapolation from the high doses used in animal studies to lower doses to which humans may be exposed, missing toxicity data, including data on the cumulative or synergistic effects of chemical exposure), and other factors that relate to the scope of the risk characterization (e.g., the MHC characterization is a screening level characterization rather than a comprehensive risk assessment). Key uncertainties in this characterization include the following:

- The risk characterization of products supplied by Enthone-OMI, MacDermid, Shipley, and, to some degree, Atotech, is based on publicly-available bath chemistry data, which do not include the identity or concentrations of chemicals considered trade secrets by chemical suppliers.⁵
- The risk estimates for occupational dermal exposure are based on limited dermal toxicity data, using oral toxicity data with oral to dermal extrapolation when dermal toxicity data were unavailable. Coupled with the high uncertainty in estimating dermal absorption rates, this could result in either over- or under-estimates of exposure and risk.

⁴ A “what-if” description represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.

⁵ Electrochemicals, LeaRonol, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary ingredient. Risk results for proprietary ingredients in chemical products submitted by these suppliers, but not chemical identities or concentrations, are included in this CTSA.

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- The risk characterization is based on modeled estimates of average, steady-state chemical concentrations in air, rather than actual monitoring data of average and peak air concentrations.
- The risk characterization does not account for any side reactions occurring in the baths, which could either underestimate exposures to toxic reaction products or overestimate exposures to toxic chemicals that react in the bath to form more benign chemicals.
- Due to resource constraints, the risk characterization does not address all types of exposures that could occur from MHC processes or the PWB industry, including short-term or long-term exposures from sudden releases due to fires, spills, or periodic releases.

The Risk Characterization section of the CTSA (Section 3.4) discusses the uncertainties in this characterization in detail.

Occupational Health Risks

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from MHC baths and for dermal exposure to MHC bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyORIZED lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyORIZED lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves⁶ and that all non-conveyORIZED lines are operated by manual hoist. Dermal exposure to line operators on non-conveyORIZED lines could occur from routine line operation and maintenance (e.g., bath replacement, filter replacement, etc.). Dermal exposure to line operators on conveyORIZED lines was assumed to occur from bath maintenance activities alone.

Risk results indicate that alternatives to the non-conveyORIZED electroless copper process pose lower occupational risks due to reduced cancer risks and to the reduced number of inhalation and dermal risk concerns for the alternatives. However, there are occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyORIZED processes. In addition, there are occupational risk concerns for dermal contact with some chemicals in the conveyORIZED electroless copper process, the non-conveyORIZED non-formaldehyde electroless copper process, and tin-palladium and organic-palladium processes for either conveyORIZED or non-conveyORIZED equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths were not identified by some suppliers and to missing toxicity or chemical property data for some chemicals known to be present in the baths.

Table 7.2 presents chemicals of concern for potential occupational risk from inhalation. Table 7.3 presents chemicals of concern for potential occupational risk from dermal contact.

⁶ Many PWB manufacturers report that their employees routinely wear gloves in the process area. However, risk from dermal contact was estimated assuming workers do not wear gloves to account for those workers who do not wear proper personal protective equipment.

Table 7.2 MHC Chemicals of Concern for Potential Occupational Inhalation Risk

Chemical ^a	Non-Conveyorized Process ^b		
	Electroless Copper	Non-Formaldehyde Electroless Copper	Tin-Palladium
Alkene Diol	✓		
Copper Chloride	✓		
Ethanolamine	✓		✓
2-Ethoxyethanol	✓		
Ethylene Glycol	✓		
Formaldehyde	✓		
Formic Acid	✓		
Methanol	✓		
Sodium Hydroxide	✓		
Sulfuric Acid^c	✓	✓	✓

^a For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), chemicals of concern that are present in all of the product lines evaluated are indicated in bold.

^b Occupational inhalation exposure from conveyorized lines was assumed to be negligible.

^c Sulfuric acid was listed on the MSDSs for all of the electroless copper lines evaluated and four of the five tin-palladium lines evaluated.

Table 7.3 MHC Chemicals of Concern for Potential Occupational Dermal Risk

Chemical ^a	Electroless Copper			Non-Formaldehyde Electroless Copper	Tin-Palladium			Organic-Palladium			
	Line Operator		Lab Tech (NC or C)		Line Operator (NC)	Line Operator		Lab Tech (NC or C)	Line Operator		Lab Tech (NC or C)
	NC	C				NC	C		NC	C	
Copper Chloride	✓	✓	✓		✓	✓	✓				
Fluoroboric Acid	✓	✓	✓		✓	✓	✓				
Formaldehyde	✓	✓									
Nitrogen Heterocycle	✓	✓									
Palladium ^b	✓	✓	✓		✓	✓	✓				
Palladium Chloride ^b					✓	✓	✓				
Palladium Salt								✓	✓	✓	
Sodium Carboxylate	✓	✓									
Sodium Chlorite	✓	✓		✓							
Stannous Chloride ^c	✓			✓	✓	✓					
Tin Salt		✓									

^a For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), chemicals of concern that are present in all of the product lines evaluated are indicated in bold.

^b Palladium or palladium chloride was listed on the MSDSs for three of the five tin-palladium lines evaluated. The MSDSs for the two other lines did not list a source of palladium. Palladium and palladium chloride are not listed on the MSDSs for all of the electroless copper lines evaluated.

^c Stannous chloride was listed on the MSDSs for four of the five tin-palladium lines evaluated. The MSDSs for the remaining line did not list a source of tin. Stannous chloride is not listed on the MSDSs for all of the electroless copper lines evaluated.

NC: Non-Conveyorized.

C: Conveyorized.

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The non-conveyorized electroless copper process contains the only non-proprietary chemical for which an occupational cancer risk has been estimated (for formaldehyde). Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The upper bound excess individual cancer risk estimate for line operators in the non-conveyorized electroless copper process from formaldehyde inhalation may be as high as one in 1,000, but may be 50 times less, or one in 50,000.⁷ Risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from three percent to 61 percent of the risk for a line operator.

Inhalation cancer risk was also estimated for one proprietary chemical, alkyl oxide, in the non-conveyorized electroless copper process. The line operator inhalation exposure estimate for alkyl oxide results in an estimated upper bound excess individual life time cancer risk of 3×10^{-7} (one in three million) based on high end exposure. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern.

Additionally, dermal cancer risks were estimated for two proprietary chemicals, cyclic ether and alkyl oxide, in the graphite and electroless copper processes. For the conveyorized graphite process, the dermal cancer risks for a line operator may be as high as 8×10^{-8} (about one in ten million) for the alkyl oxide and 1×10^{-7} (one in ten million) for the cyclic ether. The upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The cancer risks for a laboratory technician were 6×10^{-9} (one in 200 million) for alkyl oxide and 9×10^{-9} (one in 100 million) for cyclic ether.

For non-conveyorized electroless copper, the dermal cancer risks for the line operator may be as high as 4×10^{-7} (one in two million) for cyclic ether and 1×10^{-8} (one in 100 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

For conveyorized electroless copper, the dermal cancer risk for a line operator may be as high as 8×10^{-8} (about one in ten million) for cyclic ether and 4×10^{-9} (one in 200 million) for alkyl oxide. The estimated upper bound cancer risks for a laboratory technician were much less than the cancer risks for a line operator. The estimated cancer risks for a laboratory technician were 9×10^{-9} (one in 100 million) for cyclic ether and 1×10^{-10} (one in ten billion) for alkyl oxide.

Other non-proprietary chemicals in the MHC processes are suspected carcinogens. Dimethylformamide and carbon black have been determined by the International Agency for Research on Cancer (IARC) to possibly be carcinogenic to humans (IARC Group 2B). Like formaldehyde, the evidence for carcinogenic effects is based on animal data. However, unlike

⁷ To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate was provided in the Risk Characterization (Section 3.4) using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 35-fold reduction in occupational formaldehyde exposure and risk from the estimates presented here.

formaldehyde, slope factors are not available for either chemical. There are potential cancer risks to workers from both chemicals, but they cannot be quantified. Dimethylformamide is used in the electroless copper process. Workplace exposures have been estimated but cancer potency and cancer risk are unknown. Carbon black is used in the carbon and conductive ink processes. Occupational exposure due to air emissions from the carbon baths in the carbon process is expected to be negligible because this process is typically conveyORIZED and enclosed. There may be some airborne carbon black, however, from the drying oven steps. Exposures from conductive ink were not characterized. One proprietary chemical used in the electroless copper process, trisodium acetate amine B, was determined to possibly be carcinogenic to humans but does not have an established slope factor.

Public Health Risks

Public health risk was estimated for inhalation exposure only for the general populace living near a facility. Environmental releases and risk from exposure to contaminated surface water were not quantified due to a lack of data; chemical constituents and concentrations in wastewater could not be adequately characterized. Public health risk estimates are based on the assumption that emissions from both conveyORIZED and non-conveyORIZED process configurations are steady-state and vented to the outside. Risk was not characterized for short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other releases.

The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern from all MHC technologies for nearby residents. The upper bound excess individual cancer risk from formaldehyde inhalation for nearby residents from the non-conveyORIZED electroless copper process was estimated to be from approaching zero to 1×10^{-7} (one in ten million), and from approaching zero to 3×10^{-7} (one in three million) for the conveyORIZED electroless copper process. Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. The risk characterization for ambient exposure to MHC chemicals also indicates low concern from the estimated air concentrations for chronic non-cancer effects. The upper bound excess individual cancer risk for nearby residents from alkyl oxide in the conveyORIZED graphite process was estimated to be from approaching zero to 9×10^{-11} (one in 11 billion); in the non-conveyORIZED electroless copper process from approaching zero to 1×10^{-11} (one in 100 billion); and in the conveyORIZED electroless copper process from approaching zero to 3×10^{-11} (one in 33 billion). All hazard quotients are less than one for ambient exposure to the general population, and all MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations for chronic non-cancer effects.

Ecological Hazards

The CTSA methodology typically evaluates ecological risks in terms of risks to aquatic organisms in streams that receive treated or untreated effluent from manufacturing processes. Stream concentrations of MHC chemicals were not available, however, and could not be estimated because of insufficient chemical characterization of constituents and their

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concentrations in facility wastewater.⁸ To qualitatively assess risk to aquatic organisms, MHC chemicals were ranked based on aquatic toxicity values according to established EPA criteria for aquatic toxicity of high, moderate, or low concern (see Section 3.3.3).

Table 7.4 presents the number of MHC chemicals evaluated for each alternative, the number of chemicals in each alternative with aquatic toxicity of high, moderate, or low concern, the chemicals with the lowest concern concentration (CC) by alternative, and the bath concentrations of the chemicals with the lowest CC. The aquatic toxicity concern level could not be evaluated for some chemicals that have no measured aquatic toxicity data or established structure-activity relationships to estimate their aquatic toxicity. Aquatic toxicity rankings are based only on chemical toxicity to aquatic organisms, and are not an expression of risk.

Table 7.4 Aquatic Hazard Data

Alternative	No. of Chemicals Evaluated ^a	No. of Chemicals by Aquatic Hazard Concern Level ^a			Chemical with Lowest CC	Bath Concentration of Chemical With Lowest CC ^b
		High	Moderate	Low		
Electroless Copper	50 ^c	9	19	21	copper sulfate (0.00002 mg/l)	4.8 to 12 g/l
Carbon	8 ^c	2	2	3	copper sulfate (0.00002 mg/l)	5.0 g/l
Conductive Ink	11 ^c	2	1	7	silver (0.000036 mg/l)	NA
Conductive Polymer	6	0	1	5	peroxymonosulfuric acid (0.030 mg/l)	26.85 g/l
Graphite	13	3	3	7	copper sulfate (0.00002 mg/l)	2.7 g/l
Non-Formaldehyde Electroless Copper	10	3	3	4	copper sulfate (0.00002 mg/l)	22 g/l
Organic-Palladium	7	2	3	2	sodium hypophosphite (0.006 mg/l)	75 g/l ^d
Tin-Palladium	26 ^c	9	6	10	copper sulfate (0.00002 mg/l)	0.2 to 13 g/l

^a This includes chemicals from both publicly-available and proprietary data. This indicates the number of unique chemicals; there is some overlap between public and proprietary lists for electroless copper. For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals may not be present in any one product line.

^b Bath concentrations are shown as a range for technologies supplied by more than one chemical supplier and are based on publicly-available bath chemistry data.

^c No aquatic hazard data available for one chemical.

^d Chemical is in microetch bath. Concentration in bath may be overestimated, because MSDS reports both chemicals in bath (sodium persulfate and sodium bisulfate) are present in concentrations < 75 percent (< 75 g/l). NA: Not Applicable.

⁸ There are well-documented copper pollution problems associated with discharges to surface waters and many of the MHC alternatives contain copper compounds. However, there were no data available to estimate the relative concentration of copper in different MHC line effluents. In addition, no data were available for surface water concentrations of other chemicals, especially chemicals in alternatives to electroless copper processes. Thus, risk to aquatic organisms were not characterized.

A CC is the concentration of a chemical in the aquatic environment which, if exceeded, may result in significant risk to aquatic organisms. CCs were determined by dividing acute or chronic toxicity values by an assessment factor (ranging from one to 1,000) that incorporates the uncertainty associated with toxicity data. CCs are discussed in more detail in Section 3.3.3.

The number of chemicals with a high aquatic hazard concern level include nine in the electroless copper process, two in carbon, two in conductive ink, none in conductive polymer, three in graphite, three in non-formaldehyde electroless copper, two in organic-palladium, and nine in tin-palladium. However, for technologies supplied by more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals of high aquatic toxicity concern may not be present in any one product line. The lowest CC is for copper sulfate, which is found in five of the MHC technology categories: carbon, electroless copper, graphite, non-formaldehyde electroless copper, and tin-palladium. Bath concentrations of copper sulfate vary, ranging from a high of 22 g/l for the non-formaldehyde electroless copper technology to a low of 0.2 g/l in one of the tin-palladium processes (and, based on MSDS data, not present in the conductive ink, organic-palladium, or conductive polymer processes).

Process Safety

Workers can be exposed to two types of hazards affecting occupational safety and health: chemical hazards and process hazards. Workers can be at risk through exposure to chemicals and because they work in proximity to automated equipment. In order to evaluate the chemical safety hazards of the various MHC technologies, MSDSs for chemical products used with each of the MHC technologies were reviewed. Table 7.5 summarizes the hazardous properties of MHC chemical products.

Table 7.5 Hazardous Properties of MHC Chemical Products

MHC Technology	No. of MSDSs Reviewed ^b	Number of Chemical Products with Hazardous Properties ^a					
		Flammable	Combustible	Explosive	Fire Hazard	Corrosive	Oxidizer
Electroless Copper	68	7	1	1	1	29	6
Carbon	11	7	0	0	0	5	2
Conductive Ink	5	0	0	5	0	0	0
Conductive Polymer ^c	8	1	0	0	0	5	0
Graphite	12	0	0	0	1	4	1
Non-Formaldehyde Electroless Copper	19	3	0	0	0	4	3
Organic-Palladium ^c	8	0	0	0	0	0	0
Tin-Palladium	38	2	1	1	1	12	0

^a For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals with hazardous properties may not be present in any one product line.

^b Reflects the combined number of MSDSs for all product lines evaluated in a technology category.

^c Based on German equivalent of MSDS, which may not have as stringent reporting requirements as U.S. MSDS.

Table 7.5 Hazardous Properties of MHC Chemical Products (cont.)

MHC Technology	No. of MSDSs Reviewed ^b	Number of Chemical Products with Hazardous Properties ^a					
		Reactive	Unstable	Sensitizer	Acute Health Hazard	Chronic Health Hazard	Eye Damage
Electroless Copper	68	16	1	0	14	10	34
Carbon	11	2	0	0	11	9	12
Conductive Ink	5	0	0	0	0	0	2
Conductive Polymer ^c	8	0	0	0	0	0	6
Graphite	12	0	1	0	8	4	4
Non-Formaldehyde Electroless Copper	19	4	0	0	9	5	7
Organic-Palladium ^c	8	0	1	0	0	0	4
Tin-Palladium	38	3	0	2	9	5	22

^a For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals with hazardous properties may not be present in any one product line.

^b Reflects the combined number of MSDSs for all product lines evaluated in a technology category.

^c Based on German equivalent of MSDS, which may not have as stringent reporting requirements as U.S. MSDS.

Other potential chemical hazards can occur because of hazardous decomposition of chemical products, or chemical product incompatibilities with other chemicals or materials. With few exceptions, most chemical products used in MHC technologies can decompose under specific conditions to form potentially hazardous chemicals. In addition, all of the MHC processes have chemical products with incompatibilities that can pose a threat to worker safety if the proper care is not taken to prevent such occurrences.

Work-related injuries from equipment, improper use of equipment, bypassing equipment safety features, failure to use personal protective equipment, and physical stresses that may appear gradually as a result of repetitive motion are all potential process safety hazards to workers. Regardless of the technology used, of critical importance is an effective and ongoing safety training program. Characteristics of an effective worker health and safety program include:

- An employee training program.
- Employee use of personal protective equipment.
- Proper chemical storage and handling.
- Safe equipment operating procedures.

Without appropriate training, the number of worker accidents and injuries is likely to increase, regardless of the technology used. A key management responsibility is to ensure that training is not compromised by pressure to meet production demands or by cost-cutting efforts.

7.1.2 Competitiveness Summary

The competitiveness summary provides information on basic issues traditionally important to the competitiveness of a business: the performance characteristics of its products relative to industry standards; the direct and indirect costs of manufacturing its products; its need or ability to comply with environmental regulations; and factors influencing world-wide markets for its products or technologies that may affect its competitiveness. The final evaluation of a technology involves considering these traditional competitiveness issues along with issues that business leaders now know are equally important competitiveness issues: the health and environmental impacts of alternative products, processes, and technologies.

Performance

The performance of the MHC technologies was tested using production run tests. In order to complete this evaluation, PWB panels, designed to meet industry “middle-of-the-road” technology, were manufactured at one facility, run through individual MHC lines at 26 facilities, then electroplated at one facility. The panels were electrically prescreened, followed by electrical stress testing and mechanical testing, in order to distinguish variability in the performance of the MHC interconnect. The test methods used to evaluate performance were intended to indicate characteristics of a technology’s performance, not to define parameters of performance or to substitute for thorough on-site testing; the study was intended to be a “snapshot” of the technologies. The Performance Demonstration was conducted with extensive input and participation from PWB manufacturers, their suppliers, and PWB testing laboratories.

The technologies tested included electroless copper (the baseline), carbon, conductive ink⁹, conductive polymer, graphite, non-formaldehyde electroless copper, and palladium.¹⁰ The test vehicle was a 24 x 18" 0.062" 8-layer panel. (See Section 4.1 for a detailed description of the test vehicle.) Each test site received three panels for processing through the MHC line.

Test sites were submitted by suppliers of the technologies, and included production facilities, testing facilities (beta sites), and supplier testing facilities. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities (although there is no specific reason to believe that they are not representative). In addition, the number of test sites for each technology ranged from one to ten. Due to the smaller number of test sites for some technologies, results for these technologies could more easily be due to chance than the results from technologies with more test sites. Statistical relevance could not be determined.

⁹ The conductive ink test panels were processed through the MHC process and sent for testing. The supplier of the technology felt that because the test vehicle used was incompatible with the capabilities of the conductive ink technology, the test results were not indicative of the capabilities of the technology. Therefore, the results of the conductive ink technology are not reported.

¹⁰ The Performance Demonstration included both organic and tin-palladium processes in the overall palladium category.

Product performance for this study was divided into two functions: plated-through hole (PTH) cycles to failure and the integrity of the bond between the internal lands (post) and PTH (referred to as “post separation”). The PTH cycles to failure observed in this study is a function of both electrolytic plating and the MHC process. The results indicate that each MHC technology has the capability to achieve comparable (or superior) levels of performance to electroless copper. Post separation results indicated percentages of post separation that were unexpected by many members of the industry. It was apparent that all MHC technologies, including electroless copper, are susceptible to this type of failure.

Cost

Comparative costs were estimated using a hybrid cost model which combined traditional costs with simulation modeling and activity-based costs. The cost model was designed to determine the total cost of processing a specific amount of PWB through a fully operational MHC line, in this case, 350,000 surface square feet (ssf). Total costs were divided by the throughput (350,000 ssf) to determine a unit cost in \$/ssf. The cost model did not estimate start-up costs for a facility switching to an MHC alternative or the cost of other process changes that may be required to implement an MHC alternative.

The cost components considered include capital costs (primary equipment, installation, and facility costs), materials costs (limited to chemical costs), utility costs (water, electricity, and natural gas costs), wastewater cost (limited to wastewater discharge cost), production costs (production labor and chemical transport costs), and maintenance costs (tank cleanup, bath setup, sampling and analysis, and filter replacement costs). Other cost components may contribute significantly to overall costs, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs. However, Performance Demonstration results indicate that each MHC technology has the capability to achieve comparable levels of performance to electroless copper. Thus, quality costs are not expected to differ among the alternatives.

Table 7.6 presents results of the cost analysis, which indicate all of the alternatives are more economical than the non-conveyorized electroless copper process. In general, conveyorized processes cost less than non-conveyorized processes. Costs ranged from \$0.51/ssf for the baseline process to \$0.09/ssf for the conveyorized conductive polymer process. Seven process alternatives cost less than or equal to \$0.20/ssf (conveyorized carbon at \$0.18/ssf, conveyorized conductive polymer at \$0.09/ssf, conveyorized electroless copper at \$0.15/ssf, conveyorized organic-palladium at \$0.17/ssf, non-conveyorized organic-palladium at \$0.15/ssf, and conveyorized and non-conveyorized tin-palladium at \$0.12/ssf and \$0.14/ssf, respectively). Three processes cost more than \$0.20/ssf; all of these processes are non-conveyorized (non-conveyorized electroless copper at \$0.51/ssf, non-conveyorized non-formaldehyde electroless copper at \$0.40/ssf, and conveyorized graphite at \$0.22/ssf).

Table 7.6 Cost of MHC Technologies

Cost Category	Cost Components	Electroless Copper, non-conveyorized	Carbon, conveyorized	Conductive Polymer, conveyorized
Capital Cost	Primary Equipment	\$64,000	\$7,470	\$5,560
	Installation	\$11,200	\$299	\$0
	Facility	\$8,690	\$2,690	\$2,250
Material Cost	Chemicals	\$22,500	\$32,900	\$10,400
Utility Cost	Water	\$6,540	\$725	\$410
	Electricity	\$2,780	\$836	\$460
	Natural Gas	\$0	\$418	\$0
Wastewater Cost	Wastewater Discharge	\$13,700	\$1,710	\$965
Production Cost	Transportation of Material	\$737	\$446	\$673
	Labor for Line Operation	\$36,100	\$10,200	\$5,830
Maintenance Cost	Tank Cleanup	\$5,430	\$3,280	\$4,960
	Bath Setup	\$1,220	\$740	\$1,120
	Sampling and Testing	\$4,260	\$405	\$436
	Filter Replacement	\$2,800	\$116	\$376
Total Cost		\$180,000	\$62,200	\$33,400
Unit Cost (\$/ssf)		\$0.51	\$0.18	\$0.09

Cost Category	Cost Components	Electroless Copper, conveyorized	Graphite, conveyorized	Non-Formaldehyde Electroless Copper, non-conveyorized
Capital Cost	Primary Equipment	\$6,190	\$3,580	\$29,300
	Installation	\$212	\$131	\$5,120
	Facility	\$2,800	\$1,090	\$3,350
Material Cost	Chemicals	\$22,600	\$59,800	\$69,600
Utility Cost	Water	\$642	\$251	\$2,100
	Electricity	\$669	\$462	\$1,310
	Natural Gas	\$0	\$145	\$0
Wastewater Cost	Wastewater Discharge	\$1,450	\$612	\$4,520
Production Cost	Transportation of Material	\$883	\$319	\$682
	Labor for Line Operation	\$7,230	\$6,700	\$16,200
Maintenance Cost	Tank Cleanup	\$6,500	\$2,350	\$5,030
	Bath Setup	\$1,460	\$529	\$1,130
	Sampling and Testing	\$942	\$316	\$691
	Filter Replacement	\$612	\$901	\$214
Total Cost		\$52,200	\$77,200	\$139,200
Unit Cost (\$/ssf)		\$0.15	\$0.22	\$0.40

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

Table 7.6 Cost of MHC Technologies (cont.)

Cost Category	Cost Components	Organic-Palladium, conveyorized	Organic-Palladium, non-conveyorized
Capital Cost	Primary Equipment	\$5,780	\$4,160
	Installation	\$356	\$256
	Facility	\$2,220	\$1,100
Material Cost	Chemicals	\$28,900	\$27,000
Utility Cost	Water	\$635	\$758
	Electricity	\$720	\$325
	Natural Gas	\$0	\$0
Wastewater Cost	Wastewater Discharge	\$1,510	\$1,670
Production Cost	Transportation of Material	\$1,260	\$1,050
	Labor for Line Operation	\$6,530	\$7,190
Maintenance Cost	Tank Cleanup	\$9,250	\$7,710
	Bath Setup	\$2,080	\$1,740
	Sampling and Testing	\$411	\$288
	Filter Replacement	\$271	\$385
Total Cost		\$59,900	\$53,700
Unit Cost (\$/ssf)		\$0.17	\$0.15

Cost Category	Cost Components	Tin-Palladium, conveyorized	Tin-Palladium, non-conveyorized
Capital Cost	Primary Equipment	\$1,280	\$4,760
	Installation	\$205	\$381
	Facility	\$1,490	\$1,910
Material Cost	Chemicals	\$25,500	\$22,300
Utility Cost	Water	\$317	\$1,010
	Electricity	\$468	\$635
	Natural Gas	\$0	\$0
Wastewater Cost	Wastewater Discharge	\$754	\$2,340
Production Cost	Transportation of Material	\$537	\$455
	Labor for Line Operation	\$5,230	\$10,700
Maintenance Cost	Tank Cleanup	\$3,950	\$3,350
	Bath Setup	\$891	\$755
	Sampling and Testing	\$493	\$916
	Filter Replacement	\$332	\$616
Total Cost		\$41,400	\$50,100
Unit Cost (\$/ssf)		\$0.12	\$0.14

Chemical cost was the single largest component cost for nine of the ten processes. Equipment cost was the largest cost for the non-conveyorized electroless copper process. Three separate sensitivity analyses of the results indicated that chemical cost, production labor cost, and equipment cost have the greatest effect on the overall cost results.

Regulatory Status

Discharges of MHC chemicals may be restricted by federal, state or local air, water or solid waste regulations, and releases may be reportable under the federal Toxic Release Inventory program. Federal environmental regulations were reviewed to determine the federal regulatory status of MHC chemicals.¹¹ Table 7.7 lists the number of chemicals used in an MHC technology with federal environmental regulations restricting or requiring reporting of their discharges. Different chemical suppliers of a technology do not always use the same chemicals in their particular product lines. Thus, all of these chemicals may not be present in any one product line.

International Information

The total world market for PWBs is approximately \$21 billion (EPA, 1995). The U.S. and Japan are the leading suppliers of PWBs, but Hong Kong, Singapore, Taiwan, and Korea are increasing their market share. Information on the use of MHC technologies worldwide was collected to assess whether global trends affect the competitiveness of an alternative.

The alternatives to the traditional electroless copper MHC process are in use in many countries. Most of the suppliers of these alternatives have manufacturing facilities located in countries to which they sell. Several suppliers indicated the market shares of the alternatives are increasing internationally quicker than they are increasing in the U.S. The cost-effectiveness of an alternative has been the main driver causing PWB manufacturers abroad to switch from an electroless copper process to one of the newer alternatives. In addition to the increased capacity and decreased labor requirements of some of the MHC alternatives over the electroless copper process, environmental concerns also affected the process choice. For instance, the rate at which an alternative consumes water and the presence or absence of strictly regulated chemicals are two factors which have a substantial effect on the cost-effectiveness of MHC alternatives abroad. While environmental regulations do not seem to be the primary forces leading toward the adoption of the newer alternatives, it appears that the companies that supply these alternatives are taking environmental regulations and concerns into consideration when designing alternatives.

¹¹ In some cases, state or local requirements may be more restrictive than federal requirements. However, due to resource limitations, only federal regulations were reviewed.

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

Table 7.7 Regulatory Status of MHC Technologies

MHC Technology	Number of Chemicals Subject to Applicable Regulation																
	CWA				SDWA		CAA			SARA 110	EPCRA		TSCA			RCRA Waste	
	304b	307a	311	Priority Pollutant	NPDWR	NSDWR	111	112b	112r		302a	313	8d HSDR	MTL	8a PAIR	P	U
Electroless Copper	4	4	13	8	4	5	8	8	2	6	6	13	2	4	3	2	4
Carbon	1	1	3	2	1	1				1		1					
Conductive Ink	2	2		2		1	5	3		1		2	2		3		1
Conductive Polymer			3				1				1	2					
Graphite	2	1	3	1	1	1	1		1	2	2	3					
Non-Formaldehyde Electroless Copper	1	1	5	1	1	1	1	1	1	3	3	4		1	1		
Organic-Palladium			2					1	1		1	1					
Tin-Palladium	2	2	7	2	3	3	3	1	1	6	3	6		3	3		1

Abbreviations and definitions:

CAA - Clean Air Act
CAA 111 - Standards of Performance for New Stationary Sources of
Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
CWA - Clean Water Act
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CWA Priority Pollutants
EPCRA - Emergency Planning and Community Right-to-Know Act
EPCRA 302a - Extremely Hazardous Substances
EPCRA 313 - Toxic Chemical Release Inventory

RCRA - Resource Conservation and Recovery Act
RCRA P Waste - Listed acutely hazardous waste
RCRA U Waste - Listed hazardous waste
SARA - Superfund Amendments and Reauthorization Act
SARA 110 - Superfund Site Priority Contaminant
SDWA - Safe Drinking Water Act
SDWA NPDWR - National Primary Drinking Water Rules
SDWA NSDWR - National Secondary Drinking Water Rules
TSCA - Toxic Substances Control Act
TSCA 8d HSDR - Health & safety data reporting rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule

7.1.3 Resource Conservation Summary

Resources typically consumed by the operation of the MHC process include water used for rinsing panels, process chemicals used on the process line, energy used to heat process baths and power equipment, and wastewater treatment chemicals. A quantitative analysis of the energy and water consumption rates of the MHC process alternatives was performed to determine if implementing an alternative to the baseline process would reduce consumption of these resources during the manufacturing process. A quantitative analysis of both process chemical and treatment chemical consumption could not be performed due to the variability of factors that affect the consumption of these resources. Section 5.1 discusses the role the MHC process has in the consumption of these resources and the factors affecting the consumption rates.

The relative water and energy consumption rates of the MHC process alternatives were determined as follows:

- The daily water consumption rate and hourly energy consumption rate of each alternative were determined based on data collected from the IPC Workplace Practices Questionnaire.
- The operating time required to produce 350,000 ssf of PWB was determined using computer simulations models of each of the alternatives.
- The water and energy consumption rates per ssf of PWB were calculated based on the consumption rates and operating times.

Table 7.8 presents the results of these analyses.

Table 7.8 Energy and Water Consumption Rates of MHC Alternatives

Process Type	Water Consumption (gal/ssf)	Energy Consumption (Btu/ssf)
Electroless Copper, non-conveyorized (BASELINE)	11.7	573
Electroless Copper, conveyorized	1.15	138
Carbon, conveyorized	1.29	514
Conductive Polymer, conveyorized	0.73	94.7
Graphite, conveyorized	0.45	213
Non-Formaldehyde Electroless Copper, non-conveyorized	3.74	270
Organic-Palladium, non-conveyorized	1.35	66.9
Organic-Palladium, conveyorized	1.13	148
Tin-Palladium, non-conveyorized	1.80	131
Tin-Palladium, conveyorized	0.57	96.4

The energy consumption rates ranged from 66.9 Btu/ssf for the non-conveyorized organic-palladium process to 573 Btu/ssf for the non-conveyorized electroless copper process. The results indicate that all of the MHC alternatives are more energy efficient than the baseline process. They also indicate that for alternatives with both types of automation, the conveyorized version of the process is typically more energy efficient, with the notable exception of the

organic-palladium process.

An analysis of the impacts directly resulting from the consumption of energy by the MHC process showed that the generation of the required energy has environmental impacts. Pollutants released to air, water, and soil can result in damage to both human health and the environment. The consumption of natural gas tends to result in releases to the air which contribute to odor, smog, and global warming, while the generation of electricity can result in pollutant releases to all media with a wide range of possible affects. Since all of the MHC alternatives consume less energy than the baseline, they all result in less pollutant releases to the environment.

Water consumption rates ranged from 0.45 gal/ssf for the graphite process to 11.7 gal/ssf for the non-conveyorized electroless copper process. In addition, results indicate that all of the alternatives consume significantly less water than the baseline process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process.

The rate of water consumption is directly related to the rate of wastewater generation. Most PWB facilities discharge process rinse water to an on-site wastewater treatment facility for pretreatment prior to discharge to a publicly-owned treatment works (POTW). A pollution prevention analysis identified a number of pollution prevention techniques that can be used to reduce rinse water consumption. These include use of more efficient rinse configurations, use of flow control technologies, and use of electronic sensors to monitor contaminant concentrations in rinse water. Further discussion of these and other pollution prevention techniques can be found in the Pollution Prevention section of this CTSA (Section 6.1) and in PWB Project Case Study 1 (EPA, 1995).

7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

7.2.1 Introduction to Social Benefits/Costs Assessment

Social benefits/costs analysis¹² is a tool used by policy makers to systematically evaluate the impacts to all of *society* resulting from individual decisions. The decision evaluated in this analysis is the choice of an MHC technology. PWB manufacturers have a number of criteria they may use to assess which MHC technology they will use. For example, a PWB manufacturer might ask what impact their choice of an MHC alternative might have on operating costs, compliance costs, liability costs, and insurance premiums. This business planning process is unlike social benefit/cost analysis, however, because it approaches the comparison from the standpoint of the individual manufacturer and not from the standpoint of society as a whole.

A social benefits/costs analysis seeks to compare the benefits and costs of a given action, while considering both the private and external costs and benefits.¹³ Therefore, the analysis will consider both the impact of the alternative MHC processes on the manufacturer itself (private costs and benefits) and the impact the choice of an alternative has on external costs and benefits, such as reductions in environmental damage and reductions in the risk of illness for the general public. External costs are not borne by the manufacturer, rather they are the true costs to society. Table 7.9 defines a number of terms used in benefit/cost assessment, including external costs and external benefits.

¹² The term “analysis” is used here to refer to a more quantitative analysis of social benefits and costs, where a monetary value is placed on the benefits and costs to society of individual decisions. Examples of quantitative benefits/costs analyses are the regulatory impact analyses done by EPA when developing federal environmental regulations. The term “assessment” is used here to refer to a more qualitative examination of social benefits and costs. The evaluation performed in the CTSA process is more correctly termed an assessment because many of the social benefits and costs of MHC technologies are identified, but not monetized.

¹³ Private costs typically include any direct costs incurred by the decision-maker and are generally reflected in the manufacturer’s balance sheet. In contrast, external costs are incurred by parties other than the primary participants to the transaction. Economists distinguish between private and external costs because each will affect the decision-maker differently. Although external costs are real costs to some members of society, they are not incurred by the decision-maker and firms do not normally take them into account when making decisions. A common example of these “externalities” is the electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs experienced by the farmer in the form of reduced crop yields are not considered by the utility when making decisions regarding electricity production. The farmer’s losses do not appear on the utility’s balance sheet.

Table 7.9 Glossary of Benefits/Costs Analysis Terms

Term	Definition
Exposed Population	The estimated number of people from the general public or a specific population group who are exposed to a chemical through wide dispersion of a chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), use of the chemical or a product containing a chemical, or through other means.
Exposed Worker Population	The estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration.
Externality	A cost or benefit that involves a third party who is not a part of a market transaction; “a direct effect on another’s profit or welfare arising as an incidental by-product of some other person’s or firm’s legitimate activity” (Mishan, 1976). The term “externality” is a general term which can refer to either <u>external benefits</u> or <u>external costs</u> .
External Benefits	A positive effect on a third party who is not a part of a market transaction. For example, if an educational program results in behavioral changes which reduce the exposure of a population group to a disease, then an external benefit is experienced by those members of the group who did not participate in the educational program. For the example of nonsmokers exposed to second-hand smoke, an external benefit can be said to result when smokers are removed from situations in which they expose nonsmokers to tobacco smoke.
External Costs	A negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example of an external cost is the effect of second-hand smoke on nonsmokers.
Human Health Benefits	Reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air.
Human Health Costs	The cost of adverse human health effects associated with production, consumption, and disposal of a firm’s product. An example is respiratory effects from stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Illness Costs	A financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual.
Indirect Medical Costs	Indirect medical costs associated with a disease or medical condition resulting from exposure to a chemical or product. Examples would be the decreased productivity of patients suffering a disability or death and the value of pain and suffering borne by the afflicted individual and/or family and friends.

Term	Definition
Private (Internalized) Costs	The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product.
Social Costs	The total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the external costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all external costs (e.g., the costs associated with the poisoned fish).
Social Benefits	The total benefit of an activity that society receives, i.e., the sum of the private benefits and the external benefits. For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the external benefit (benefit society receives from reduced waste).
Willingness-to-Pay	Estimates used in benefits valuation are intended to encompass the full value of avoiding a health or environmental effect. For human health effects, the components of willingness-to-pay include the value of avoiding pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of life.

Private benefits of the alternative MHC processes may include increased profits resulting from improved worker productivity and company image, a reduction in energy use, or reduced property and health insurance costs due to the use of less hazardous chemicals. External benefits may include a reduction in pollutants emitted to the environment or reduced use of natural resources. Costs of the alternative MHC processes may include private costs such as changes in operating expenses and external costs such as an increase in human health risks and ecological damage. Several of the benefit categories considered in this assessment share elements of both private and external costs and benefits. For example, use of an alternative may result in natural resource savings. Such a benefit may result in private benefits in the form of reduced water usage and a resultant reduction in payments for water as well as external benefits in the form of reduced consumption of shared resources.

7.2.2 Benefits/Costs Methodology and Data Availability

The methodology for conducting a social benefits/costs assessment can be broken down into four general steps: 1) obtain information on the relative human and environmental risk, performance, cost, process safety hazards, and energy and natural resource requirements of the baseline and the alternatives; 2) construct matrices of the data collected; 3) when possible, monetize the values presented within the matrices; and 4) compare the data generated for the alternative and the baseline in order to produce an estimate of net social benefits. Section 7.1 presented the results of the first task by summarizing risk, competitiveness, and conservation information for the baseline and alternative MHC technologies. Section 7.2.3 presents matrices of private benefits and costs data, while Section 7.2.4 presents information relevant to external benefits and costs. Section 7.2.5 presents the private and external benefits and costs together to produce an estimate of net social benefits.

Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline MHC technologies, allowing identification of the technology whose use results in the largest net social benefit. This is particularly true for national estimates of net social benefits or costs. However, because of resource and data limitations and because individual users of this CTSA will need to apply results to their own particular situations, the analysis presents a qualitative description of the risks and other external effects associated with each substitute technology compared to the baseline. Benefits derived from a reduction in risk are described and discussed, but not quantified. Nonetheless, the information presented can be very useful in the decision-making process. A few examples are provided to qualitatively illustrate some of the benefit considerations. Personnel in each individual facility will need to examine the information presented, weigh each piece according to facility and community characteristics, and develop an independent choice.

7.2.3 Private Benefits and Costs

While it is difficult to obtain an overall number to express the private benefits and costs of alternative MHC processes, some data were quantifiable. For example, the cost analysis estimated the average manufacturing costs of the MHC technologies, including the average capital costs (primary equipment, installation, and facility cost), materials costs (limited to chemical costs), utility costs (water, electricity, and natural gas costs), wastewater costs (limited to wastewater discharge cost), production cost (production labor and chemical transport costs), and maintenance costs (tank cleanup, bath setup, sampling and analysis, and filter replacement costs). Other cost components may contribute significantly to overall manufacturing costs, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs.

Differences in the manufacturing costs estimated in the cost analysis are summarized below. However, in order to determine the overall private benefit/cost comparison, a qualitative discussion of the data is also necessary. Following the discussion of manufacturing costs are discussions of private costs associated with occupational and population health risks and other private costs or benefits that could not be monetized but are important to the decision-making process.

Manufacturing Costs

Table 7.10 presents the percent change in manufacturing costs for the MHC alternatives as compared to the baseline. Only costs that were quantified in the cost analysis are presented. All of the alternatives result in cost savings in the form of lower total costs; most of the alternatives result in cost savings in almost every cost category. In addition, the Performance Demonstration determined that each alternative has the capability to achieve comparable levels of performance to electroless copper, thus quality costs are considered equal among the alternatives. This is important to consider in a benefits/costs analysis since changes in performance necessarily result in changed costs in the market. This is not the case in this assessment since all alternatives yield comparable performance results.

Table 7.10 Differences in Private Costs^a

MHC Technology	Average Cost		Capital Cost		Chemical Cost		Water Cost		Electricity Cost	
	\$/ssf	% change	\$/ssf	% change	\$/ssf	% change	\$/ssf	% change	\$/ssf	% change
Electroless Copper, non-conveyorized (BASELINE)	\$ 0.51		\$ 0.24		\$ 0.06		\$ 0.02		\$ 0.008	
Electroless Copper, conveyorized	\$ 0.15	-71	\$ 0.03	-88	\$ 0.06	0	\$ 0.002	-90	\$ 0.002	-75
Carbon, conveyorized	\$ 0.18	-65	\$ 0.03	-88	\$ 0.10	+66	\$ 0.002	-90	\$ 0.001	-88
Conductive Polymer, conveyorized	\$ 0.09	-82	\$ 0.02	-92	\$ 0.03	-50	\$ 0.001	-95	\$ 0.001	-88
Graphite, conveyorized	\$ 0.22	-57	\$ 0.01	-96	\$ 0.17	+183	\$ 0.001	-95	\$ 0.004	-50
Non-Formaldehyde Electroless Copper, non-conveyorized	\$ 0.40	-22	\$ 0.11	-54	\$ 0.20	+233	\$ 0.01	-50	\$ 0.004	-50
Organic-Palladium, non-conveyorized	\$ 0.15	-71	\$ 0.02	-92	\$ 0.08	+33	\$ 0.002	-90	\$ 0.001	-88
Organic-Palladium, conveyorized	\$ 0.17	-67	\$ 0.02	-92	\$ 0.08	+33	\$ 0.002	-90	\$ 0.002	-75
Tin-Palladium, non-conveyorized	\$ 0.14	-73	\$ 0.02	-92	\$ 0.06	0	\$ 0.003	-85	\$ 0.002	-75
Tin-Palladium, conveyorized	\$ 0.12	-77	\$ 0.01	-96	\$ 0.07	+17	\$ 0.001	-95	\$ 0.001	-88
MHC Technology	Natural Gas Cost		Wastewater Cost		Production Cost		Maintenance Cost			
	\$/ssf	% change	\$/ssf	% change	\$/ssf	% change	\$/ssf	% change		
Electroless Copper, non-conveyorized (BASELINE)	\$ -		\$ 0.04		\$ 0.11		\$ 0.04			
Electroless Copper, conveyorized	\$ -	NA	\$ 0.004	-90	\$ 0.02	-82	\$ 0.03	-25		
Carbon, conveyorized	\$ 0.001	NA	\$ 0.005	-88	\$ 0.03	-73	\$ 0.01	-75		
Conductive Polymer, conveyorized	\$ -	NA	\$ 0.003	-93	\$ 0.02	-82	\$ 0.02	-50		
Graphite, conveyorized	\$ 0.0004	NA	\$ 0.002	-95	\$ 0.02	-82	\$ 0.01	-75		
Non-Formaldehyde Electroless Copper, non-conveyorized	\$ -	NA	\$ 0.01	-75	\$ 0.05	-55	\$ 0.02	-50		
Organic-Palladium, non-conveyorized	\$ -	NA	\$ 0.005	-88	\$ 0.02	-82	\$ 0.03	-25		
Organic-Palladium, conveyorized	\$ -	NA	\$ 0.004	-90	\$ 0.02	-82	\$ 0.03	-25		
Tin-Palladium, non-conveyorized	\$ -	NA	\$ 0.007	-83	\$ 0.03	-73	\$ 0.02	-50		
Tin-Palladium, conveyorized	\$ -	NA	\$ 0.002	-95	\$ 0.02	-82	\$ 0.02	-50		

^a Table lists costs and percent change in cost from the baseline.

NA: Not Applicable, % change cannot be calculated because baseline has zero cost in this cost category.

Occupational Health Risks

Reduced risks to workers can be considered both a private and external benefit. Private worker benefits include reductions in worker sick days and reductions in health insurance costs to the PWB manufacturer. External worker benefits include reductions in medical costs to workers in addition to reductions in pain and suffering associated with work-related illness. External benefits from reduced risk to workers are discussed in more detail in Section 7.2.4.

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from MHC baths and for dermal exposure to MHC bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyORIZED lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyORIZED lines. Dermal exposure estimates are based on the assumption that workers do not wear gloves and that all non-conveyORIZED lines are operated by manual hoist. Dermal exposure to workers on non-conveyORIZED lines could occur from routine line operation and maintenance (i.e., bath replacement, filter replacement, etc.). Dermal exposure to workers on conveyORIZED lines was assumed to occur from bath maintenance alone. Worker dermal exposure to all MHC technologies can be easily minimized by using proper protective equipment such as gloves during MHC line operation and maintenance. In addition, many PWB manufacturers report that their employees routinely wear gloves in the process area. Nonetheless, risk from dermal contact was estimated assuming workers do not wear gloves to account for those workers who do not wear proper personal protective equipment.

Because some parts of the exposure assessment for both inhalation and dermal exposures qualify as “what-if” descriptors,¹⁴ the entire assessment should be considered “what-if.” Table 7.11 summarizes the number of chemicals of concern for the exposure pathways evaluated and lists the number of suspected carcinogens in each technology.

Based on the results of the risk characterization, it appears that alternatives to the non-conveyORIZED electroless copper process have private benefits due to reduced occupational risks. However, there are also occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyORIZED processes. In addition, there are occupational dermal exposure risk concerns for some chemicals in the conveyORIZED electroless copper process, the non-conveyORIZED non-formaldehyde electroless copper, and the tin-palladium and organic palladium processes with conveyORIZED or non-conveyORIZED equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths are not included¹⁵ for chemical products submitted by Atotech (except one proprietary chemical in one of Atotech’s technologies), Enthone-OMI, MacDermid and Shipley,

¹⁴ A “what-if” risk descriptor represents an exposure estimate based on postulated questions, making assumptions based on limited data where the distribution is unknown.

¹⁵ Electrochemicals, LeaRonald, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary chemical ingredient. Risk results for proprietary chemicals in chemical products but not chemical identities or concentrations, are included in this CTSA.

and to a lack of toxicity or chemical property data for some chemicals known to be present in the baths.

Table 7.11 Summary of Occupational Hazards, Exposures, and Risks of Potential Concern

MHC Technology	No. of Chemicals of Concern by Pathway ^a		No. of Suspected Carcinogens
	Inhalation	Dermal	
Electroless Copper, non-conveyorized (BASELINE)	10	8	5 ^b
Electroless Copper, conveyorized	0	8	5 ^b
Carbon, conveyorized	0	0	1
Conductive Polymer, conveyorized	0	0	0
Graphite, conveyorized	0	0	2 ^c
Non-Formaldehyde Electroless Copper, non-conveyorized	1	2	0
Organic-Palladium, non-conveyorized	0	1	0
Organic-Palladium, conveyorized	0	1	0
Tin-Palladium, non-conveyorized	2	5	0
Tin-Palladium, conveyorized	0	5	0

^a Number of chemicals of concern for an MHC line operator (the most exposed individual).

^b Includes formaldehyde (EPA Group B1, probable human carcinogen) and dimethylformamide (IARC Group 2B, possible human carcinogen). Also included are the proprietary chemicals, cyclic ether, alkyl oxide, and trisodium acetate amine B.

^c Includes the proprietary chemicals, cyclic ether and alkyl oxide.

Occupational cancer risks were estimated for inhalation exposure to formaldehyde and alkyl oxide in the non-conveyorized electroless copper process, and for dermal exposure to cyclic ether and alkyl oxide in the conveyorized graphite, conveyorized electroless copper, and non-conveyorized electroless copper processes. Formaldehyde has been classified by EPA as Group B1, a Probable Human Carcinogen. Results indicate clear concern for formaldehyde inhalation exposure; the upper bound excess individual cancer risk estimate for line operators in the non-conveyorized electroless copper process from formaldehyde inhalation may be as high as one in 1,000, but may be 50 times less, or one in 50,000.¹⁶ Inhalation risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from three percent to 61 percent of the risk for a line operator. Occupational risks associated with dermal and inhalation exposure to cyclic ether and alkyl oxide were below 1×10^{-6} (one in one million) for the graphite and electroless copper processes and are therefore considered to be of low concern. The occupational cancer risks associated with exposure to dimethylformamide, carbon black, and trisodium acetate amine B could not be quantified because cancer slope factors have not been determined for these chemicals.

¹⁶ To provide further information on the possible variation of formaldehyde exposure and risk, an additional exposure estimate was provided in the Risk Characterization (Section 3.4) using average and median values (rather than high-end) as would be done for a central tendency exposure estimate. This results in approximately a 35-fold reduction in occupational formaldehyde exposure and risk from the estimates presented here.

Public Health Risks

In addition to worker exposure, members of the general public may be exposed to MHC chemicals due to their close physical proximity to a PWB plant or due to the wide dispersion of chemicals. Reduced public health risks can also be considered both a private and external benefit. Private benefits include reductions in potential liability costs; external benefits include reductions in medical costs. External benefits from reduced public health risk are discussed in more detail in Section 7.2.4.

Public health risk was estimated for inhalation exposure only for the general populace living near a facility. Environmental releases and risk from exposure to contaminated surface water were not quantified due to a lack of data; chemical constituents and concentrations in wastewater could not be adequately characterized. Public health risk estimates are based on the assumption that emissions from both conveyORIZED and non-conveyORIZED process configurations are steady-state and vented to the outside. Risk was not characterized for short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other periodic release.

The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern from all MHC technologies for nearby residents. The estimated upper bound excess individual cancer risk for nearby residents exposed to emissions from the non-conveyORIZED electroless copper process ranged from values approaching zero to 1×10^{-7} (one in ten million) for formaldehyde, and from approaching zero to 1×10^{-11} (one in 100 billion) for the alkyl oxide. The estimated cancer risk values for the conveyORIZED electroless copper process ranged from values approaching zero to 3×10^{-7} (one in three million) for formaldehyde, and from approaching zero to 3×10^{-11} (one in 33 billion) for the alkyl oxide. The estimated cancer risk for nearby residents exposed to emissions from the conveyORIZED graphite process ranged from values approaching zero to 9×10^{-11} (one in 11 billion) for the alkyl oxide. The risk characterization for ambient exposure to other MHC chemicals also indicated low concern from the estimated air concentrations for chronic non-cancer effects.

These results suggest little change in public health risks and, thus, private benefits or costs if a facility switched from the baseline to an MHC alternative. However, it is important to note that it was not within the scope of this comparison to assess all community health risks. The risk characterization did not address all types of exposures that could occur from MHC processes or the PWB industry, including short-term or long-term exposures from sudden releases due to spills, fires, or periodic releases.

Ecological Risks

MHC chemicals are potentially damaging to terrestrial and aquatic ecosystems, resulting in both private costs borne by the manufacturers and external costs borne by society. Private costs could include increased liability costs while external costs could include loss of ecosystem diversity and reductions in the recreational value of streams and rivers. The CTSA evaluated the ecological risks of the baseline and alternatives in terms of aquatic toxicity hazards. Aquatic risk could not be estimated because chemical concentrations in MHC line effluents and streams were not available and could not be estimated. It is not possible to reliably estimate concentrations only from the MHC process since most PWB manufacturers combine MHC effluents with

effluents from other process lines.

Table 7.12 presents the number of chemicals in each technology with a high aquatic hazard concern level. There are well documented copper pollution problems associated with discharges to surface waters and many of the MHC alternatives contain copper compounds. The lowest CC for an MHC chemical is for copper sulfate, which is found in five of the MHC technology categories: electroless copper, carbon, graphite, non-formaldehyde electroless copper, and tin-palladium. Bath concentrations of copper sulfate vary, ranging from a high of 22 g/l for the non-formaldehyde electroless copper technology to a low of 0.2 g/l in one of the tin-palladium processes (and, based on MSDS data, not present in the conductive ink, conductive polymer, or organic-palladium processes). Because the concentration of copper sulfate in different MHC line effluents is not known, the benefits or costs of using one of these MHC alternatives cannot be assessed. For example, the non-formaldehyde electroless copper process has a higher bath concentration of copper sulfate than the baseline; however, because the non-formaldehyde electroless copper process does not contain the chelator EDTA, more copper may be removed during wastewater treatment.

Table 7.12 Number of Chemicals with High Aquatic Hazard Concern Level

MHC Technology	No. of Chemicals
Electroless Copper	9
Carbon	2
Conductive Ink	2
Conductive Polymer	0
Graphite	3
Non-Formaldehyde Electroless Copper	3
Organic-Palladium	2
Tin-Palladium	9

Plant-Wide Benefits or Costs

The CTSA did not determine the PWB plant-wide benefits or costs that could occur from implementing an alternative to the baseline MHC technology. However, a recent study of the Davila International PWB plant in Mountain View, California, identified a number of changes to the PWB manufacturing process that were only possible when an alternative to electroless copper was installed. These changes reduced copper pollution and water use, resulting in cost savings. A companion document to this publication, *Implementing Cleaner Technologies in the Printed Wiring Board Industry: Making Holes Conductive* (EPA, 1997), describes some of the systems benefits that can occur from implementing an MHC technology.

Improvements in the efficiency of the overall system not only provide private benefits, but also social benefits.

In addition, the baseline MHC process is a production bottleneck in many shops, but the alternative MHC technologies have substantially improved production rates. Thus, switching to an alternative improves the competitiveness of a PWB manufacturer by enabling the same

number of boards to be produced faster or even enabling an increase in overall production capacity. However, the increased productivity could have social costs if increased production rates cause increased pollution rates in other process steps. Greater production rates in all the processes should be coupled with pollution prevention measures.

Another cost could be incurred if increased production results in increased amounts of scrap board. The Performance Demonstration determined that all of the alternatives have the potential to perform as well as electroless copper if operated properly. However, vendors and manufacturers who have implemented the alternatives stress the importance of taking a “whole-process” view of new MHC technology installation. Process changes upstream or downstream may be necessary to optimize alternative MHC processes (EPA, 1997). This is also important from a societal perspective because an increase in scrap boards can increase pollution generation off-site. In particular, citizens groups are concerned about potential dioxin emissions from the off-site process of secondary metal smelting which recycles scrap boards (Smith and Karras, 1997).

Other Private Benefits and Costs

Table 7.13 gives additional examples of private costs and benefits that could not be quantified. These include wastewater treatment, solid waste disposal, compliance, liability, insurance and worker illness costs, and improvements in company image that accrue from implementing a substitute. Some of these were mentioned above, but are included in the table due to their importance to overall benefits and costs.

7.2.4 External Benefits and Costs

External costs are those costs that are not taken into account in the manufacturer’s pricing and manufacturing decisions. These costs are commonly referred to as “externalities” and are costs that are borne by society and not by the individuals who are part of a market transaction. These costs can result from a number of different avenues in the manufacturing process. For example, if a manufacturer uses a large quantity of a non-renewable resource during the manufacturing process, society will eventually bear the costs for the depletion of this natural resource. Another example of an external cost is an increase in population health effects resulting from the emission of chemicals from a manufacturing facility. The manufacturer does not pay for any illnesses that occur outside the plant that result from air emissions. Society must bear these costs in the form of medical care payments or higher insurance premiums.

Conversely, external benefits are those that do not benefit the manufacturer directly. For example, an alternative that uses less water results in both private and external benefits. The manufacturer pays less for water; society in general benefits from less use of a scarce resource. This type of example is why particular aspects of the MHC process are discussed in terms of both private benefits and costs and external benefits and costs.

Table 7.13 Examples of Private Costs and Benefits Not Quantified

Category	Description of Potential Costs or Benefits
Wastewater Treatment	<p>Alternatives to the baseline MHC technology may provide cost savings by reducing the quantity and improving the treatability of process wastewaters. In turn, these cost savings can enable the implementation of other pollution prevention measures. Alternatives to the baseline process use less rinse water and, consequently, produce less wastewater. In addition, the elimination of the chelator EDTA found in electroless copper processes simplifies the removal of heavy metal ions by precipitation. However, other processes may contain complexing agents that form bonds with metal ions, also making them difficult to remove. For example, the graphite technology contains the complexing agent ammonia. All of these factors—reducing the quantity of wastewater, reducing the amount of chelated or complexed metals in wastewater effluents, and enabling pollution prevention measures—provide social benefits as well as private benefits.</p>
Solid Waste Disposal	<p>All of the alternatives result in the generation of sludge, off-specification PWBs, and other solid wastes, such as spent bath filters. These waste streams must be recycled or disposed of, some of them as hazardous waste. For example, many PWB manufacturers send sludges to a recycler to reclaim metals in the sludge. Sludges that cannot be effectively recycled will most likely have to be landfilled. It is likely that the manufacturer will incur costs in order to recycle or landfill these sludges and other solid wastes, however these costs were not quantified. Three categories of MHC technologies generate RCRA-listed wastes, including electroless copper, conductive ink, and tin-palladium. However, other technologies may generate wastes considered hazardous because they exhibit certain characteristics. In addition, most facilities combine wastewater from various process lines prior to on-site treatment, including wastewater from electroplating operations. Wastewater treatment sludge from copper electroplating operations is a RCRA F006 hazardous waste. Reducing the volume and toxicity of solid waste also provides social benefits.</p>
Compliance Costs	<p>The cost of complying with all environmental and safety regulations affecting the MHC process line was not quantified. However, chemicals and wastes from the MHC alternatives are subject to fewer overall federal environmental regulations than the baseline, suggesting that implementing an alternative could potentially reduce compliance costs. It is more difficult to assess the relative cost of complying with OSHA requirements, because the alternatives pose similar occupational safety hazards (although non-automated, non-conveyorized equipment may pose less overall process hazards than working with mechanized equipment).</p>
Liability, Insurance, and Worker Illness Costs	<p>Based on the results of the risk characterization, it appears that alternatives to the baseline process pose lower overall risk to human health and the environment. Implementing an alternative could cause private benefits in the form of lower liability and insurance cost and increased employee productivity from decreases in incidences of illness. Clearly, alternatives with reduced risk also provide social benefits (discussed in Section 7.2.4).</p>
Company Image	<p>Many businesses are finding that using cleaner technologies results in less tangible benefits, such as an improved company image and improved community relations. While it is difficult to put a monetary value on these benefits, they should be considered in the decision-making process.</p>

The potential external benefits associated with the use of an MHC alternative include: reduced health risk for workers and the general public, reduced ecological risk, and reduced use of energy and natural resources. Another potential externality is the influence a technology choice has on the number of PWB plant jobs in a community. Each of these is discussed in turn below.

Occupational Health Risks

Section 7.2.3 discussed risk characterization results for occupational exposures. Based on the results of the risk characterization, it appears that alternatives to the non-conveyorized electroless copper process have private benefits due to reduced occupational risks. However, there are also occupational inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper and tin-palladium non-conveyorized processes. In addition, there are occupational dermal exposure risk concerns for some chemicals in the conveyorized electroless copper, the non-conveyorized non-formaldehyde electroless copper, and organic-palladium and tin-palladium processes with conveyorized or non-conveyorized equipment. Finally, occupational health risks could not be quantified for one or more of the chemicals used in each of the MHC technologies. This is due to the fact that proprietary chemicals in the baths were not identified by some suppliers¹⁷ and to missing toxicity or chemical property data for some chemicals known to occur in the baths.

Reduced occupational risks provide significant private as well as social benefits. Private benefits can include reduced insurance and liability costs, which may be readily quantifiable for an individual manufacturer. External benefits are not as easily quantifiable. They may result from the workers themselves having reduced costs such as decreased insurance premiums or medical payments or society having reduced costs based on the structure of the insurance industry.

Data exist on the cost of avoiding or mitigating certain illnesses that are linked to exposures to MHC chemicals. These cost estimates can serve as indicators of the potential benefits associated with switching to technologies using less toxic chemicals or with reduced exposures. Table 7.14 lists potential health effects associated with MHC chemicals of concern. It is important to note that, except for cancer risk from formaldehyde, the risk characterization did not link exposures of concern with particular adverse health outcomes or with the number of incidences of adverse health outcomes.¹⁸ Thus, the net benefit of illnesses avoided by switching to an MHC alternative cannot be calculated.

¹⁷ Electrochemicals, LeaRonald, and Solution Technology Systems provided information on proprietary chemical ingredients to the project for evaluation in the risk characterization. Atotech provided information on one proprietary chemical used in the product line. Enthone-OMI, MacDermid, and Shipley declined to provide proprietary chemical information. Risk results for proprietary chemicals, as available, but not chemical identities or concentrations, are included in this CTSA.

¹⁸ Cancer risk from formaldehyde exposure was expressed as a probability, but the exposure assessment did not determine the size of the potentially exposed population (e.g., number of MHC line operators and others working in the process area). This information would be necessary to estimate the number of illnesses avoided by switching to an alternative from the baseline.

Table 7.14 Potential Health Effects Associated with MHC Chemicals of Concern

Chemical of Concern	Alternatives with Exposure Levels of Concern	Pathway of Concern^a	Potential Health Effects
Alkene Diol	Electroless Copper	inhalation	Exposure to low levels may result in irritation of the throat and upper respiratory tract.
Copper Chloride	Electroless Copper	inhalation	Long-term exposure to copper dust can irritate nose, mouth, eyes and cause dizziness. Long-term exposure to high levels of copper may cause liver damage. Copper is not known to cause cancer. The seriousness of the effects of copper can be expected to increase with both level and length of exposure.
		dermal	No data were located for health effects from dermal exposure in humans.
Ethanolamine	Electroless Copper, Tin-Palladium	inhalation	Ethanolamine is a strong irritant. Animal studies showed that the chemical is an irritant to the respiratory tract, eyes, and skin. No data were located for inhalation exposure in humans.
2-Ethoxyethanol	Electroless Copper	inhalation	In animal studies 2-ethoxyethanol caused harmful blood effects, including destruction of red blood cells and releases of hemoglobin (hemolysis), and male reproductive effects at high exposure levels. The seriousness of the effects of the chemical can be expected to increase with both level and length of exposure. No data were located for inhalation exposure in humans.
Ethylene Glycol	Electroless Copper	inhalation	In humans, low levels of vapors produce throat and upper respiratory irritation. When ethylene glycol breaks down in the body, it forms chemicals that crystallize and that can collect in the body and prevent kidneys from working. The seriousness of the effects of the chemical can be expected to increase with both level and length of exposure.
Fluoroboric Acid	Electroless Copper, Tin-Palladium	dermal	Fluoroboric acid in humans produces strong caustic effects leading to structural damage to skin and eyes.

7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

Chemical of Concern	Alternatives with Exposure Levels of Concern	Pathway of Concern ^a	Potential Health Effects
Formaldehyde	Electroless Copper	inhalation	EPA has classified formaldehyde as a probable human carcinogen (EPA Group B1). Inhalation exposure to formaldehyde in animals produces nasal cancer at low levels. In humans, exposure to formaldehyde at low levels in air produces skin irritation and throat and upper respiratory irritation. The seriousness of these effects can be expected to increase with both level and length of exposure.
		dermal	In humans, exposure to formaldehyde at low levels in air produces skin irritation. The seriousness of these effects can be expected to increase with both level and length of exposure.
Methanol	Electroless Copper	inhalation	Long-term exposure to methanol vapors can cause headache, irritated eyes and dizziness at high levels. No harmful effects were seen when monkeys were exposed to highly concentrated vapors of methanol. When methanol breaks down in the tissues, it forms chemicals that can collect in the tissues or blood and lead to changes in the interior of the eye causing blindness.
Nitrogen Heterocycle	Electroless Copper	dermal	No data were located for health effects from dermal exposure in humans.
Palladium	Electroless Copper, Tin-Palladium	dermal	No specific information was located for dermal exposure of palladium in humans.
Palladium Chloride	Tin-Palladium	dermal	Long-term dermal exposure to palladium chloride in humans produces contact dermatitis.
Palladium Salt	Organic-Palladium	dermal	Exposure may result in skin irritation and sensitivity.
Sodium Carboxylate	Electroless Copper	dermal	No data were located for health effects from dermal exposure in humans.
Sodium Chlorite	Electroless Copper, Non-Formaldehyde Electroless Copper	dermal	No specific information was located for health effects from dermal exposure to sodium chlorite in humans. Animal studies showed that the chemical produces moderate irritation of skin and eyes.
Stannous Chloride	Electroless Copper, Non-Formaldehyde Electroless Copper, Tin-Palladium	dermal	Mild irritation of the skin and mucous membrane has been shown from inorganic tin salts. However, no specific information was located for dermal exposure to stannous chloride in humans. Stannous chloride is only expected to be harmful at high doses; it is poorly absorbed and enters and leaves the body rapidly.

Chemical of Concern	Alternatives with Exposure Levels of Concern	Pathway of Concern ^a	Potential Health Effects
Sulfuric Acid	Electroless Copper, Non-Formaldehyde Electroless Copper, Tin-Palladium	inhalation	Sulfuric acid is a very strong acid and can cause structural damage to skin and eyes. Humans exposed to sulfuric acid mist at low levels in air experience a choking sensation and irritation of lower respiratory passages.
Tin Salt	Electroless Copper	dermal	No data were located for health effects from dermal exposure in humans. Inorganic tin compounds may irritate the eyes, nose, throat, and skin.

^a Inhalation concerns only apply to non-conveyorized processes. Dermal concerns may apply to non-conveyorized and/or conveyorized processes (see Table 7.3).

Health endpoints potentially associated with MHC chemicals of concern include: nasal cancer (for formaldehyde), eye irritation, and headaches. The draft EPA publication, *The Medical Costs of Selected Illnesses Related to Pollutant Exposure* (EPA, 1996), evaluates the medical cost of some forms of cancer, but not nasal cancer. Other publications have estimated the economic costs associated with eye irritation and headaches. These data are discussed below.

Benefits of Avoiding Illnesses Potentially Linked to MHC Chemical Exposure

This section presents estimates of the economic costs of some of the illnesses or symptoms associated with exposure to MHC chemicals. To the extent that MHC chemicals are not the only factor contributing toward the illnesses described, individual costs may overestimate the potential benefits to society from substituting alternative MHC technologies for the baseline electroless copper process. For example, other PWB manufacturing process steps may also contribute toward adverse worker health effects. The following discussion focuses on the external benefits of reductions in illness. However, private benefits may be accrued by PWB manufacturers through increased worker productivity and a reduction in liability and health care insurance costs. While reductions in insurance premiums as a result of pollution prevention are not currently widespread, the opportunity exists for changes in the future.

Exposure to several of the chemicals of concern is associated with eye irritation. Other potential health effects include headaches and dizziness. The economic literature provides estimates of the costs associated with eye irritation and headaches. An analysis by Unsworth and Neumann summarizes the existing literature on the costs of illness based on estimates of how much an individual would be willing to pay to avoid certain acute effects for one symptom day (Unsworth and Neumann, 1993). These estimates are based upon a survey approach designed to elicit estimates of individual willingness-to-pay to avoid a single incidence and not the lifetime costs of treating a disease. Table 7.15 presents a summary of the low, mid-range, and high estimates of individual willingness-to-pay to avoid eye irritation and headaches. These estimates provide an indication of the benefit per affected individual that would accrue to society if switching to a substitute MHC technology reduced the incidence of these health endpoints.

Table 7.15 Estimated Willingness-to-Pay to Avoid Morbidity Effects for One Symptom Day (1995 dollars)

Health Endpoint	Low	Mid-Range	High
Eye Irritation ^a	\$21	\$21	\$46
Headache ^b	\$2	\$13	\$67

^a Tolley, G.S., et al. January 1986. *Valuation of Reductions in Human Health Symptoms and Risks*. University of Chicago. Final Report for the U.S. EPA. As cited in Unsworth, Robert E. and James E. Neumann, Industrial Economics, Incorporated. Memorandum to Jim DeMocker, Office of Policy Analysis and Review. *Review of Existing Value of Morbidity Avoidance Estimates: Draft Valuation Document*. September 30, 1993.

^b Dickie, M., et al. September 1987. *Improving Accuracy and Reducing Costs of Environmental Benefit Assessments*. U.S. EPA, Washington, DC. Tolley, G.S., et al. *Valuation of Reductions in Human Health Symptoms and Risks*. January 1986. University of Chicago. Final Report for the U.S. EPA. As cited in Unsworth, Robert E. and James E. Neumann, Industrial Economics, Incorporated. Memorandum to Jim DeMocker, Office of Policy Analysis and Review. *Review of Existing Value of Morbidity Avoidance Estimates: Draft Valuation Document*. September 30, 1993.

Public Health Risk

Section 7.2.3 discussed public health risks from MHC chemical exposure. The risk characterization identified no concerns for the general public through ambient air exposure with the possible exception of formaldehyde exposure from electroless copper processes. While the study found little difference among the alternatives for those public health risks that were assessed, it was not within the scope of this comparison to assess all community health risks. Risk was not characterized for exposure via other pathways (e.g., drinking water, fish ingestion, etc.) or short-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other periodic release.

Ecological Hazards

The CTSA evaluated the ecological risks of the baseline and alternatives in terms of aquatic toxicity hazards. Aquatic risk could not be estimated because chemical concentrations in MHC line effluents and streams were not available and could not be estimated. Reduced aquatic hazards can provide significant external benefits, including improved ecosystem diversity, improved supplies for commercial fisheries, and improved recreational values of water resources. There are well documented aquatic toxicity problems associated with copper discharges to receiving waters, but this assessment was unable to determine the relative reduction in copper or other toxic discharges from the baseline to the alternatives. Five processes contain copper sulfate, the most toxic of the copper compounds found in MHC lines, and other processes contain copper chloride. In order to evaluate the private and external benefits or costs of implementing an alternative, PWB manufacturers should attempt to determine what the changes in their mass loading of copper or other toxic discharges would be.¹⁹

¹⁹ Copper discharges are a particular problem because of the cumulative mass loadings of copper discharges from a number of different industry sectors, including the PWB industry.

Energy and Natural Resources Consumption

Table 7.16 summarizes the water and energy consumption rates and percent changes in consumption from the baseline to the MHC alternatives. All of the alternatives use substantially less energy and water per ssf of PWB produced, with the exception of the carbon technology which only has a slight decrease (< ten percent) in energy use from the baseline. While manufacturers face direct costs from the use of energy and water in the manufacturing process, society as a whole also experiences costs from this usage. For energy consumption, these types of externalities can come in the form of increased emissions to the air either during the initial manufacturing of the energy or the MHC processes themselves. These emissions include CO₂, SO_x, NO₂, CO, H₂SO₄, and particulate matter. Table 5.9 in the Energy Impacts section (Section 5.2) details the pollution resulting from the generation of energy consumed by MHC alternatives. Environmental and human health concerns associated with these pollutants include global warming, smog, acid rain, and health effects from toxic chemical exposure.

Table 7.16 Energy and Water Consumption of MHC Technologies

MHC Technology	Water Consumption		Energy Consumption	
	gal/ssf	% change	Btu/ssf	% change
Electroless Copper, non-conveyorized (BASELINE)	11.7		573	
Electroless Copper, conveyorized	1.15	-90	138	-76
Carbon, conveyorized	1.29	-89	514	-9.6
Conductive Polymer, conveyorized	0.73	-94	94.7	-83
Graphite, conveyorized	0.45	-96	213	-63
Non-Formaldehyde Electroless Copper, non-conveyorized	3.74	-68	270	-53
Organic-Palladium, non-conveyorized	1.35	-88	66.9	-88
Organic-Palladium, conveyorized	1.13	-90	148	-74
Tin-Palladium, non-conveyorized	1.80	-85	131	-77
Tin-Palladium, conveyorized	0.57	-95	96.4	-83

In addition to increased pollution, the higher energy usage of the baseline also results in external costs in the form of depletion of natural resources. Some form of raw resource is required to make electricity, whether it be coal, natural gas or oil, and these resources are non-renewable. While it is true that the price of the electricity to the manufacturer takes into account the actual raw materials costs, the price of electricity does not take into account the depletion of the natural resource base. As a result, eventually society will have to bear the costs for the depletion of these natural resources.

The use of water and consequent generation of wastewater also results in external costs to society. While the private costs of this water usage are included in the cost estimates in Table 7.10, the external costs are not. The private costs of water usage account for the actual quantities of water used in the MHC process by each different technology. However, clean water is quickly becoming a scarce resource, and activities that utilize water therefore impose external costs on society. These costs can come in the form of higher water costs for the surrounding area or for higher costs paid to treatment facilities to clean the water. These costs may also come in the

form of decreased water quality available to society. In fact, in Germany, PWB manufacturers are required to use their wastewater at least three times before disposing of it because of the scarcity of water.

Effects on Jobs

The results of the cost analysis suggest that alternative MHC technologies are generally more efficient than the baseline process due to decreased cycle times. In addition, labor costs are one of the biggest factors causing the alternatives to be cheaper. Neither the Cost Analysis nor the CTSA analyzed the potential for job losses resulting from implementing an alternative. However, if job losses were to occur, this could be a significant external cost to the community. For example, in Silicon Valley, community groups are striving to retain clean, safe jobs through directing cost savings to environmental improvements that create or retain jobs. While the effects on jobs of wide-scale adoption of an alternative were not analyzed, anecdotal evidence from facilities that have switched from the baseline suggests that jobs are not lost, but workers are freed to work on other tasks (Keenan, 1997). In addition, one incentive for PWB manufacturers to invest in the MHC alternatives is the increased production capacity of the alternatives. Some PWB manufacturers who choose to purchase new capital-intensive equipment are doing so because of growth, and would not be expected to lay off workers (Keenan, 1997).

Other External Benefits or Costs

In addition to the externalities discussed above, the baseline and MHC alternatives can have other external benefits and costs. Many of these were discussed in Table 7.13 because many factors share elements of both private and external benefits and costs. For example, regulated chemicals result in a compliance cost to industry, but they also result in an enforcement cost to society whose governments are responsible for ensuring environmental requirements are met.

7.2.5 Summary of Benefits and Costs

The objective of a social benefits/costs assessment is to identify those technologies or decisions that maximize net benefits. Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline MHC technologies in terms of a single unit (e.g., dollars) and calculate the net benefits of using an alternative instead of the baseline technology. Due to data limitations, however, this assessment presents a qualitative description of the benefits and costs associated with each technology compared to the baseline. Table 7.17 compares some of the relative benefits and costs of each technology to the baseline, including production costs, worker health risks, public health risks, aquatic toxicity concerns, water consumption, and energy consumption. The effects on jobs of wide-scale adoption of an alternative are not included in the table because the potential for job losses was not evaluated in the CTSA. However, the results of the Cost Analysis suggest there are significantly reduced labor requirements for the alternatives. Clearly, the loss of manufacturing jobs would be a significant external cost to the community and should be considered by PWB manufacturers when choosing an MHC technology.

7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

Table 7.17 Relative Benefits and Costs of MHC Alternatives Versus Baseline

MHC Technology	Production Costs (\$/ssf)	Number of Chemicals of Concern ^a				Water Consumption (gal/ssf)	Energy Consumption (Btu/ssf)
		Worker Health Risks ^{b,c,d}		Public Health Risks ^e	High Aquatic Toxicity Concern ^{b,f}		
		Inhalation	Dermal	Inhalation			
Electroless Copper, non-conveyorized (BASELINE)	\$0.51	10	8	0 ^g	9	11.7	573
Electroless Copper, conveyorized	↗↗	↗↗	↔	↔ ^h	↔	↗↗	↗↗
Carbon, conveyorized	↗↗	↗↗	↗↗	↗	↔	↗↗	↔
Conductive Polymer, conveyorized	↗↗	↗↗	↗↗	↗	↗	↗↗	↗↗
Graphite, conveyorized	↗↗	↗↗	↗↗ ⁱ	↗ ^j	↔	↗↗	↗↗
Non-Formaldehyde Electroless Copper, non-conveyorized	↗	↗	↗	↗	↔	↗↗	↗↗
Organic-Palladium, non-conveyorized	↗↗	↗↗	↗	↗	↗	↗↗	↗↗
Organic-Palladium, conveyorized	↗↗	↗↗	↗	↗	↗	↗↗	↗↗
Tin-Palladium, non-conveyorized	↗↗	↗	↗	↗	↔	↗↗	↗↗
Tin-Palladium, conveyorized	↗↗	↗↗	↗	↗	↔	↗↗	↗↗

^a Includes proprietary chemicals that were identified.

^b For technologies with more than one chemical supplier (i.e., electroless copper, graphite, and tin-palladium) all chemicals may not be present in any one product line.

^c For the most exposed individual (i.e., an MHC line operator).

^d Because the risk characterization did not estimate the number of incidences of adverse health outcomes, the amount of reduced risk benefit cannot be quantified. However, based on the level of formaldehyde risk and the number of chemicals of concern for the baseline, it appears all of the alternatives have at least some reduced risk benefits from the baseline.

^e Because the risk characterization did not estimate the number of incidences of adverse health outcomes, the amount of reduced risk benefit cannot be quantified. However, based on the level of formaldehyde risk for the baseline, it appears all of the alternatives except the conveyorized electroless copper process have at least some reduced risk benefits from the baseline.

^f Technologies using copper sulfate were assigned a neutral benefit or cost; other technologies were assigned “some benefit” because none of their chemicals are as toxic to aquatic organisms as copper sulfate. This assessment is based on hazard, not risk.

^g No chemical risks above concern levels. However, it should be noted that formaldehyde cancer risks as high as 1×10^{-7} were estimated.

^h No chemical risks above concern levels. However, it should be noted that formaldehyde cancer risks as high as 3×10^{-7} were estimated.

ⁱ No chemical risks above concern levels. However, it should be noted that proprietary chemical cancer risks as high as 1×10^{-7} were estimated.

^j No chemical risks above concern levels. However, it should be noted that proprietary chemical cancer risks as high as 9×10^{-11} were estimated.

Key:

↔ - Neutral, less than 20 percent increase or decrease from baseline.

↗ - Some benefit, 20 to <50 percent decrease from baseline.

↗↗ - Greater benefit, 50 percent or greater decrease from baseline.

7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

While each alternative presents a mixture of private and external benefits and costs, it appears that each of the alternatives have social benefits as compared to the baseline. In addition, at least three of the alternatives appear to have social benefits over the baseline in every category, but public health risk. These are the conveyorized conductive polymer process and both conveyorized and non-conveyorized organic-palladium processes. However, the supplier of these technologies has declined to provide complete information on proprietary chemical ingredients for evaluation in the risk characterization, meaning health risks could not be fully assessed. Little or no improvement is seen in public health risks because concern levels were very low for all technologies, although formaldehyde cancer risks as high as from 1×10^{-7} to 3×10^{-7} were estimated for non-conveyorized and conveyorized electroless copper processes, respectively.

In terms of worker health risks, conveyorized processes have the greatest benefits for reduced worker inhalation exposure to bath chemicals; they are enclosed and vented to the atmosphere. However, dermal contact from bath maintenance activities can be of concern regardless of the equipment configuration for electroless copper, organic palladium, and tin-palladium processes. No data were available for conveyorized non-formaldehyde electroless copper processes (the same chemical formulations were assumed), but the non-conveyorized version of this technology also has chemicals with dermal contact concerns.

The relative benefits and costs of technologies from changes in aquatic toxicity concerns were more difficult to assess because only aquatic hazards were evaluated and not risk. Several of the technologies contain copper sulfate, which has a very low aquatic toxicity concern concentration (0.00002 mg/l). However, all of the technologies contain other chemicals with high aquatic toxicity concern levels, although these chemicals are not as toxic as copper sulfate.

All of the alternatives provide significant social benefits in terms of energy and water consumption, with the exception of energy consumption for the carbon technology. The drying ovens used with this technology cause this technology to consume nearly as much energy per ssf as the baseline.

7.3 TECHNOLOGY SUMMARY PROFILES

This section of the CTSA presents summary profiles of each of the MHC technologies. The profiles summarize key information from various sections of the CTSA, including the following:

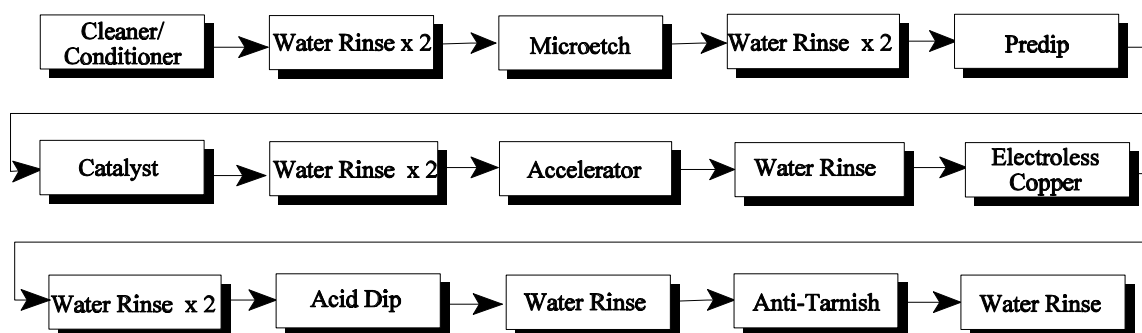
- Generic process steps, typical bath sequences and equipment configurations evaluated in the CTSA.
- Human health and environmental hazards data and risk concerns for non-proprietary chemicals.
- Production costs and resource (water and energy) consumption data.
- Federal environmental regulations affecting chemicals in each of the technologies.
- The conclusions of the social benefits/costs assessment.

The first summary profile (Section 7.3.1) presents data for both the baseline process and the conveyorized electroless copper process. Sections 7.3.2 through 7.3.7 present data for the carbon, conductive polymer, graphite, non-formaldehyde electroless copper, organic-palladium, and tin-palladium technologies, respectively.

As discussed in Section 7.2, each of the alternatives appear to provide private as well as external benefits compared to the non-conveyorized electroless copper process (the baseline process), though net benefits could not be assessed without a more thorough assessment of effects on jobs and wages. However, the actual decision of whether or not to implement an alternative occurs outside of the CTSA process. Individual decision-makers may consider a number of additional factors, such as their individual business circumstances and community characteristics, together with the information presented in this CTSA.

7.3.1 Electroless Copper Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Non-conveyorized (the baseline process) and conveyorized.

Risk Characterization

Table 7.18 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the electroless copper technology. The risk characterization identified occupational inhalation risk concerns for ten chemicals in non-conveyorized electroless copper processes and dermal risk concerns for eight chemicals for either equipment configuration. No public health risk concerns were identified for the pathways evaluated, although formaldehyde cancer risks as high as 1×10^{-7} and 3×10^{-7} were estimated for non-conveyorized and conveyorized electroless copper processes, respectively.

Table 7.18 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Electroless Copper Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b				Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c		Dermal ^d			
	Toxicity ^c (mg/m ³)	Risk Concerns	Toxicity ^e (mg/kg-d)	Risk Concerns		
Alkene Diol	NR ^f	no	NR	no	Probable human carcinogen ^g	NR
Alkyl Oxide	NR ^f	no	NR	no	Possible/probable human carcinogen ^g	NR
Ammonium Chloride	ND	NA	1691(NOAEI)	no	none	0.05
Benzotriazole	ND	NE	109 (LOAEL)	no	none	0.023 ^h
Boric Acid	ND	NE	62.5 (LOAEL)	no	none	0.022
Copper (I) Chloride ⁱ	0.6 (LOAEL)	yes	0.07 (LOAEL)	yes	EPA Class D	0.0004
Copper Sulfate ⁱ	ND	NE	ND	NE	none	0.00002
Cyclic Ether	ND	NA	NR	yes	none	NR
Dimethylaminoborane	ND	NE	ND	NE	none	0.007 ^j
Dimethylformamide	0.03 (RfC)	no	125 (LOAEL)	no	IARC Group 2B ^k	0.12
Ethanolamine	12.7 (LOAEL)	yes	320 (NOAEL)	no	none	0.075
2-Ethoxyethanol	0.2 (RfC)	yes	0.4 (RfD)	no	none	5.0
Ethylenediaminetetraacetic Acid (EDTA)	ND	NA	ND	NE	none	0.41
Ethylene Glycol	31	yes	2 (RfD)	no	none	3.3
Fluoroboric Acid	ND	NE	0.77	yes	none	0.125
Formaldehyde	0.1 ppm (LOAEL)	yes	0.2 (RfD)	yes	EPA Class B1 IARC Group 2A	0.0067
Formic Acid	59.2 (NOAEL)	yes	ND	NE	none	0.08
Hydrochloric Acid ^l	0.007 (RfC)	no	ND	NE ^m	IARC Group 3	0.1
Hydrogen Peroxide	79	no	630 (NOAEL)	no	IARC Group 3	1.2
Hydroxyacetic Acid	ND	NE	250 (NOAEL)	no	none	1 ⁿ

Chemical ^a	Human Health Hazard and Occupational Risks ^b				Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c		Dermal ^d			
	Toxicity ^c (mg/m ³)	Risk Concerns	Toxicity ^e (mg/kg-d)	Risk Concerns		
Isopropyl Alcohol; or 2-Propanol	980 (NOAEL)	no	100 (NOAEL)	no	none	9.0
m-Nitrobenzene Sulfonic Acid	ND	NE	ND	NE	none	5.0
Magnesium Carbonate	Generally regarded as safe (U.S. FDA as cited in HSDB, 1995)				none	1.0 ^j
Methanol	1,596 - 10,640	yes	0.5 (RfD)	no	none	17
Nitrogen Heterocycle	ND	NA	NR	yes	none	NR
Palladium	ND	NA	0.95 (LOAEL)	yes	none	0.00014
Peroxymonosulfuric Acid	ND	NA	ND	NE	none	0.030 ^j
Potassium Bisulfate	ND	NE	ND	NE	none	>1.0 ^j
Potassium Cyanide	ND	NE	0.05 (RfD)	no	none	0.79
Potassium Hydroxide	7.1	no	ND	NE	none	0.08
Potassium Persulfate	ND	NE	ND	NE	none	0.92
Potassium Sodium Tartrate	Generally regarded as safe (U.S. FDA as cited in HSDB, 1996)				none	ND
Potassium Sulfate	15 (TC _{Lo})	no	ND	NE	none	0.11
Sodium Bisulfate	ND	NA	ND	NE	none	0.058
Sodium Carbonate	10 (NOAEL)	no	ND	NE	none	2.4
Sodium Carboxylate	ND	NA	NR	yes	none	NR
Sodium Chlorite	ND	NA	10 (NOAEL)	yes	none	0.00016
Sodium Cyanide	ND	NE	0.04 (RfD)	no	none	0.79
Sodium Hydroxide	2 (LOAEL)	yes	ND	NE	none	2.5
Sodium Hypophosphite	ND	NA	ND	NE	none	0.006 ^j
Sodium Sulfate	ND	NA	420 (NOAEL)	no	none	0.81
Stannous Chloride	ND	NA	0.62 (RfD)	yes	none	0.0009
Sulfuric Acid	0.066 (NOAEL)	yes	ND	NE ^m	none	2.0
Tartaric Acid	ND	NE	8.7	no	none	1.0
Tin Salt	ND	NA	NR	no	none	NR
p-Toluene Sulfonic Acid	ND	NA	ND	ND	none	1.0 ^j
Triethanolamine	ND	NA	32 (LOAEL)	no	none	0.18

^a Chemicals in bold were in all electroless copper technologies evaluated, unless otherwise noted.

^b Risk concerns are for MHC line operators (the most exposed individual).

^c Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.

^d Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.

7.3 TECHNOLOGY SUMMARY PROFILES

^e Toxicity measure is RfC, RfD, NOAEL, or LOAEL as indicated. If not indicated, the type of toxicity measure was not specified in the available information, but assumed to be LOAEL in risk calculations.

^f Toxicity data are available but not reported in order to protect proprietary chemical identities.

^g Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.

^h Estimated using ECOSAR computer software, based on structure-activity relationship.

ⁱ Either copper (I) chloride or copper sulfate was in all electroless copper lines evaluated.

^j Estimated by EPA's Structure-Activity Team.

^k Cancer risk was not evaluated because no slope (unit risk) factor is available.

^l Hydrochloric acid was listed on the MSDSs for five of six electroless copper lines.

^m Chronic dermal toxicity data are not typically developed for strong acids.

ND: No Data. No toxicity measure available for this pathway.

NE: Not Evaluated; due to lack of toxicity measure.

NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1×10^{-3} torr) and is not used in any air-sparged bath.

NR: Not Reported.

Performance

The performance of the electroless copper technology was demonstrated at seven test facilities, including six sites using non-conveyorized equipment and one site using conveyorized equipment. Performance test results were not differentiated by the type of equipment configuration used. The Performance Demonstration determined that each of the alternative technologies has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

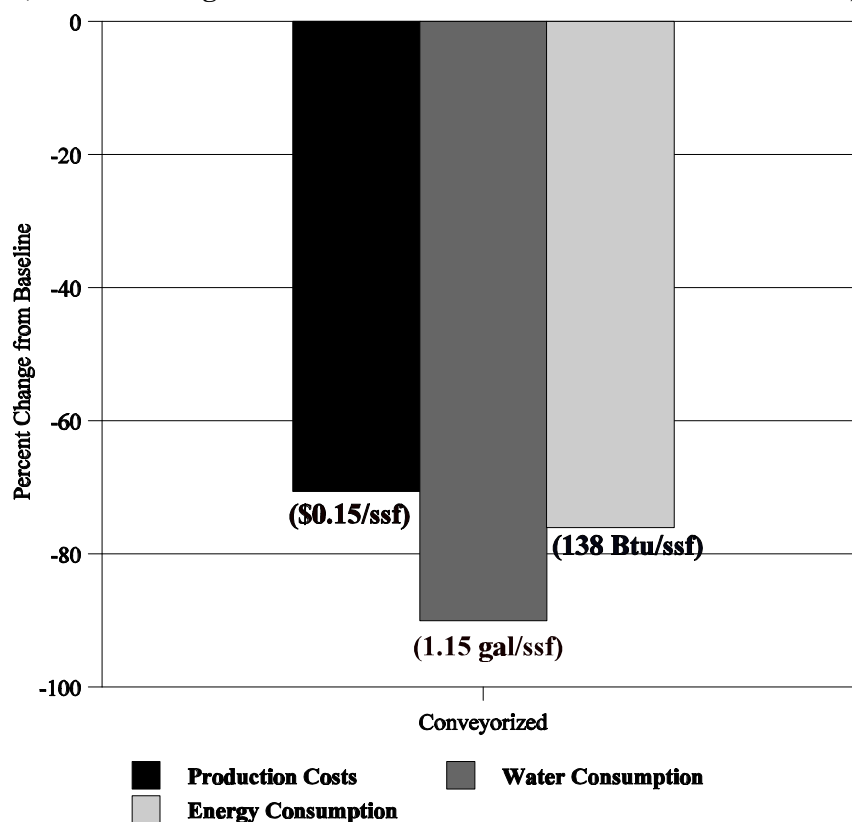
Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. Average manufacturing costs for the baseline process (the non-conveyorized electroless copper process) were \$0.51/ssf, while water and energy consumption were 11.7 gal/ssf and 573 Btu/ssf, respectively. However, the conveyorized electroless copper process consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized electroless copper). Figure 7.1 lists the results of the production costs and resource consumption analyses for the conveyorized electroless copper process and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by 71 percent, 90 percent, and 76 percent, respectively.

Regulatory Concerns

Chemicals contained in the electroless copper technology are regulated by the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Superfund Amendments and Reauthorization Act, the Emergency Planning and Community Right-to-Know Act, and the Toxic Substances Control Act. In addition, the technology generates wastes listed as hazardous (P or U wastes) under RCRA.

Figure 7.1 Production Costs and Resource Consumption of Conveyorized Electroless Copper Technology

(Percent Change from Baseline with Actual Values in Parentheses)

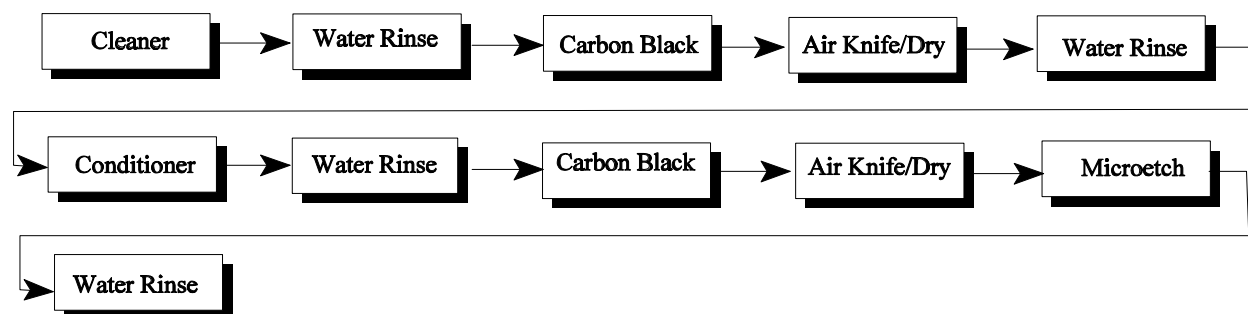


Social Benefits and Costs

A qualitative assessment of the private and external (e.g., social) benefits and costs of the baseline and alternative technologies was performed to determine if there would be net benefits to society if PWB manufacturers switched to alternative technologies from the baseline. It was concluded that all of the alternatives, including the conveyorized electroless copper process, appear to have net societal benefits, though net benefits could not be completely assessed without a more thorough assessment of effects on jobs and wages. For the conveyorized electroless copper process this is due to reduced occupational inhalation risk as well as to lower production costs and to reduced consumption of limited resources (water and energy).

7.3.2 Carbon Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Conveyorized.

Risk Characterization

Table 7.19 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the carbon technology. The risk characterization identified no human health risk concerns for the pathways evaluated. However, proprietary chemicals are not included in this assessment and toxicity data were not available for some chemicals in carbon technology baths.

Performance

The performance of the carbon technology was demonstrated at two test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resource (water and energy) consumed. This information was used with a hybrid cost model of traditional costs (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. The conveyorized carbon technology consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized electroless copper). Figure 7.2 lists the results of these analyses and illustrates the percent changes in costs and resources consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by 65 percent, 89 percent, and 9.6 percent, respectively.

Table 7.19 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Carbon Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b			Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c	Dermal			
	Toxicity ^d (mg/m ³)	Toxicity ^d (mg/kg-d)	Risk Concerns		
Carbon Black	7.2 (LOAEL)	ND	NE	IARC 2B	ND
Copper Sulfate	ND	ND	NE	none	0.00002
Ethanolamine	12.7 (LOAEL)	320 (NOAEL)	no	none	0.075
Ethylene Glycol	31	2 (RfD)	no	none	3.3
Potassium Carbonate	ND	ND	NE ^e	none	>3.0
Potassium Hydroxide	7.1	ND	NE	none	0.08
Sodium Persulfate	ND	ND	NE	none	0.065
Sulfuric Acid	0.066 (NOAEL)	ND	NE ^f	none	2.0

^a Only one carbon technology was evaluated. All chemicals listed were present in that product line.

^b Risk evaluated for conveyORIZED process only. Risk concerns are for line operator (the most exposed individual).

^c Exposure and risk not calculated. Inhalation exposure and risk from fully enclosed, conveyORIZED process is assumed to be negligible.

^d Toxicity measure is RfC, RfD, NOAEL, or LOAEL, as indicated. If not indicated, the type of toxicity measure was not specified in the available information, but assumed to be a LOAEL in risk calculations.

^e Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.

^f Chronic dermal toxicity data are not typically developed for strong acids.

ND: No Data. No toxicity measure available for this pathway.

NE: Not Evaluated; due to lack of toxicity measure.

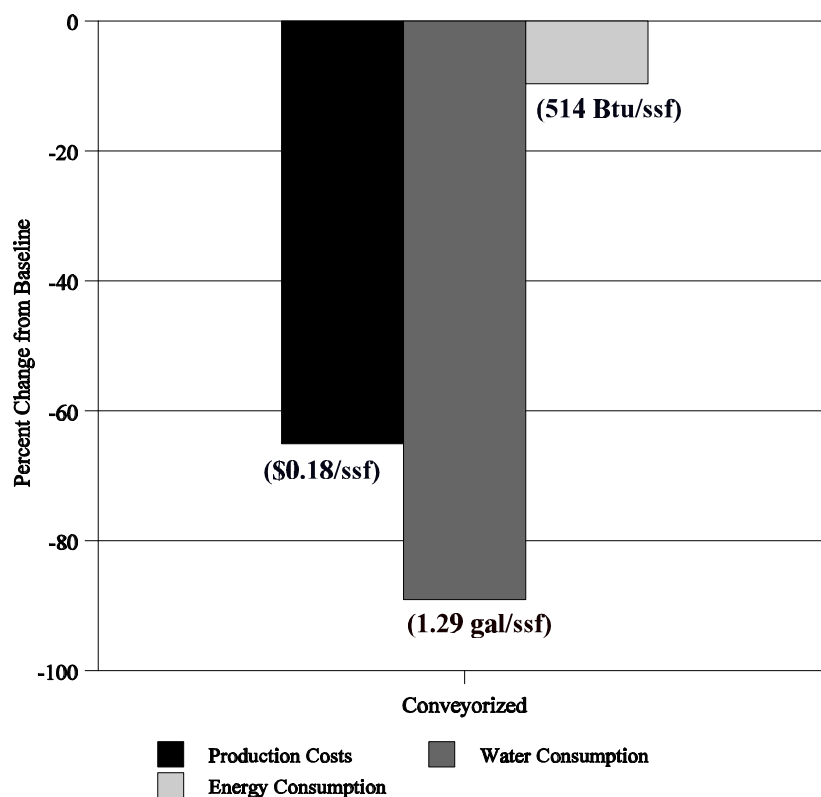
Regulatory Concerns

Chemicals contained in the carbon technology are regulated by the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Superfund Amendments and Reauthorization Act, and the Emergency Planning and Community Right-to-Know Act. The technology does not generate wastes listed as hazardous (P or U waste) under RCRA, but some wastes may have RCRA hazardous characteristics.

Social Benefits and Costs

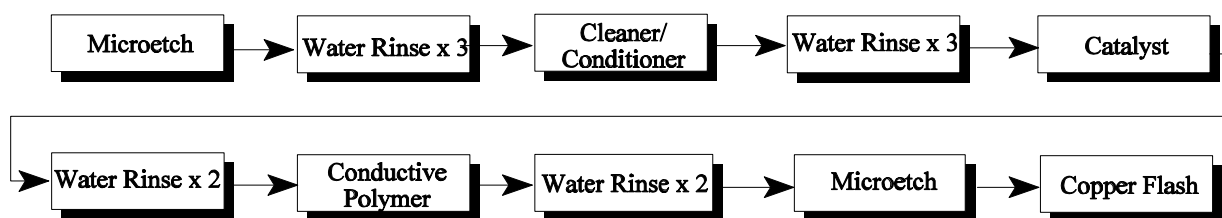
A qualitative assessment of the private and external benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the carbon technology from the baseline. Among other factors, this is due to lower occupational risks to workers and to reduced consumption of limited resources (water and, to a lesser degree, energy).

Figure 7.2 Production Costs and Resource Consumption of Carbon Technology
(Percent Change from Baseline with Actual Values in Parentheses)



7.3.3 Conductive Polymer Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Conveyorized.

Risk Characterization

Table 7.20 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the conductive polymer technology. The risk characterization identified no human health risk concerns for the pathways evaluated. However, proprietary chemicals are not included in this assessment and no toxicity data are available for some chemicals in conductive polymer technology baths.

Table 7.20 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Conductive Polymer Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b			Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^e	Dermal			
	Toxocity ^d (mg/m ³)	Toxicity ^d (mg/kg-d)	Risk Concerns		
1H-Pyrrole	ND	ND	NE	none	0.21
Peroxymonosulfuric Acid	ND	ND ^e	ND	none	0.030
Phosphoric Acid	ND	ND	NE ^f	none	0.138
Sodium Carbonate	10 (NOAEL)	ND	NE	none	2.4
Sodium Hydroxide	2 (LOAEL)	ND	NE	none	2.5
Sulfuric Acid	0.066 (NOAEL)	ND	NE ^f	none	2.0

^a Only one conductive polymer technology was evaluated. All chemicals were present in that product line.

^b Risk evaluated for conveyorized process only. Risk concerns are for line operator (the most exposed individual).

^c Exposure and risk not calculated. Inhalation exposure and risk from fully enclosed, conveyorized process is assumed to be negligible.

^d Toxicity measure is RfC, RfD, NOAEL, or LOAEL, as indicated. If not indicated, the type of toxicity measure was not specified in the available information, but assumed to be a LOAEL in risk calculations.

^e Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.

^f Chronic dermal toxicity data are not typically developed for strong acids.

ND: No Data. No toxicity measure available for this pathway.

NE: Not Evaluated; due to lack of toxicity measure.

Performance

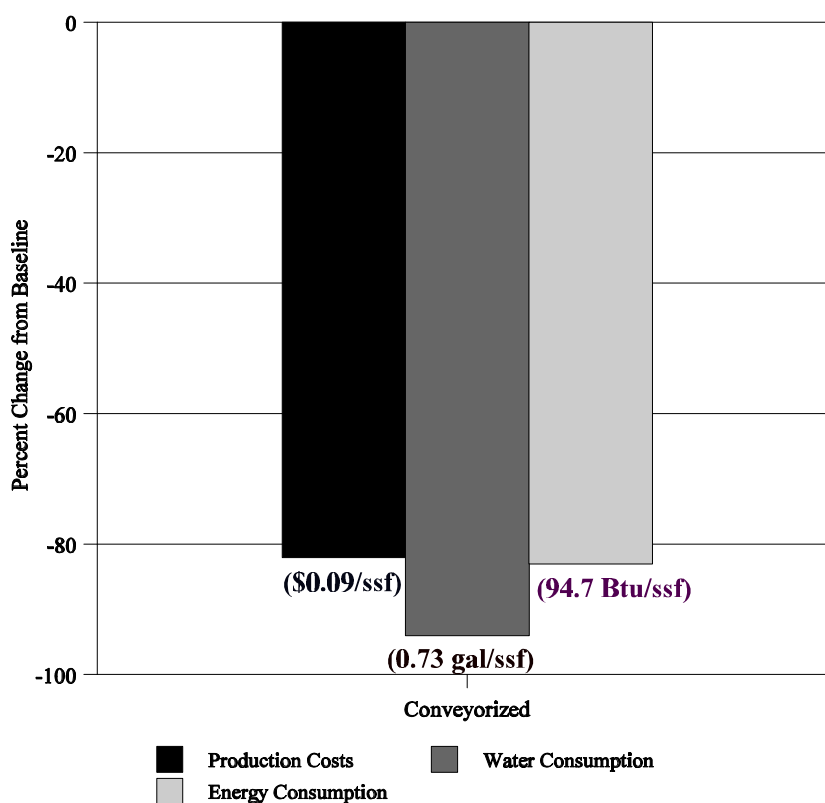
The performance of the conductive polymer technology was demonstrated at one test facility. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional costs (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

The conveyorized conductive polymer technology consumed less water and energy than the baseline process (non-conveyorized electroless copper). Figure 7.3 lists the results of these analyses and illustrates the percent changes in resources consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by 82 percent, 94 percent, and 83 percent, respectively.

Figure 7.3 Production Costs and Resource Consumption of Conductive Polymer Technology
(Percent Change from Baseline with Actual Values in Parentheses)



Regulatory Concerns

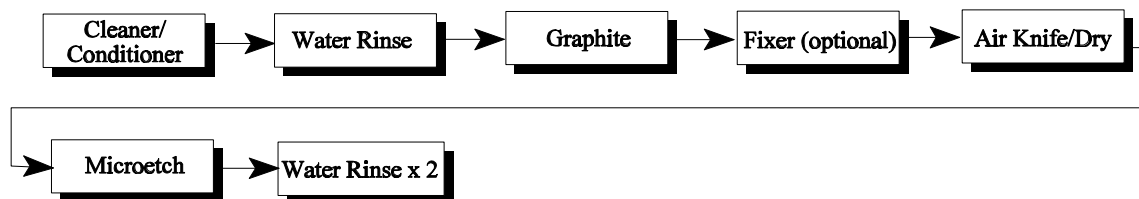
Chemicals contained in the conductive polymer technology are regulated by the Clean Water Act, the Clean Air Act, and the Emergency Planning and Community Right-to-Know Act. The technology does not generate wastes listed as hazardous (P or U waste) under RCRA, but some wastes may have RCRA hazardous characteristics.

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the conductive polymer technology from the baseline. Among other factors, this is due to lower occupational risks to workers and to reduced consumption of limited resources (water and energy).

7.3.4 Graphite Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Conveyorized.

Risk Characterization

Table 7.21 summarizes human and environmental hazards and risk concerns for chemicals in the graphite technology. The risk characterization identified no human health risk concerns for the pathways evaluated. However, the identification of proprietary chemicals was only provided by one of the two companies that submitted information concerning the graphite process. In addition, toxicity data was not available from some chemicals in the graphite technology baths.

Performance

The performance of the graphite technology was demonstrated at three test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional costs (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. The conveyorized graphite technology consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized electroless copper). Figure 7.4 lists the results of these analyses and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by 57 percent, 96 percent, and 63 percent, respectively.

Regulatory Concerns

Chemicals contained in the graphite technology are regulated by the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Superfund Amendments and Reauthorization Act, and the Emergency Planning and Community Right-to-Know Act. The technology does not generate wastes listed as hazardous (P or U waste) under RCRA, but some wastes may have RCRA hazardous characteristics.

Table 7.21 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Graphite Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b			Carcinogenicity Weight-of Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c	Dermal			
	Toxicity ^d (mg/m ³)	Toxicity ^d (mg/kg-d)	Risk Concerns		
Alkyl Oxide	ND	NR ^e	no	Probable human carcinogen ^f	NR
Ammonia	0.1 (RfC)	ND	NE	none	0.0042
Copper Sulfate; or Cupric Sulfate	ND	ND	NE	none	0.00002
Cyclic Ether	ND	NR ^e	no	Possible/ probable human carcinogen ^f	NR
Ethanolamine	12.7 (LOAEL)	320 (NOAEL)	no	none	0.075
Graphite	56 (LOAEL)	ND	NE	none	ND ^g
Peroxymonosulfuric Acid	ND	ND ^h	NE	none	0.030 ⁱ
Potassium Carbonate	ND	ND ^h	NE	none	>3.0
Sodium Persulfate	ND	ND	NE	none	0.065
Sulfuric Acid	0.066 (NOAEL)	ND	NE ^j	none	2.0

^a Chemicals in bold were in both graphite technologies evaluated.

^b Risk evaluated for conveyorized process only. Risk concerns are for line operator (the most exposed individual).

^c Exposure and risk not calculated. Inhalation exposure and risk from fully enclosed, conveyorized process is assumed to be negligible.

^d Toxicity measure is RfC, RfD, NOAEL, or LOAEL, as indicated.

^e Toxicity data are available but not reported in order to protect proprietary chemical identities.

^f Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.

^g Not expected to be toxic at saturation levels (based on EPA Structure-Activity Team evaluation).

^h Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.

ⁱ Estimated by EPA's Structure-Activity Team.

^j Chronic toxicity data are not typically developed for strong acids.

ND: No Data. No toxicity measure available for this pathway.

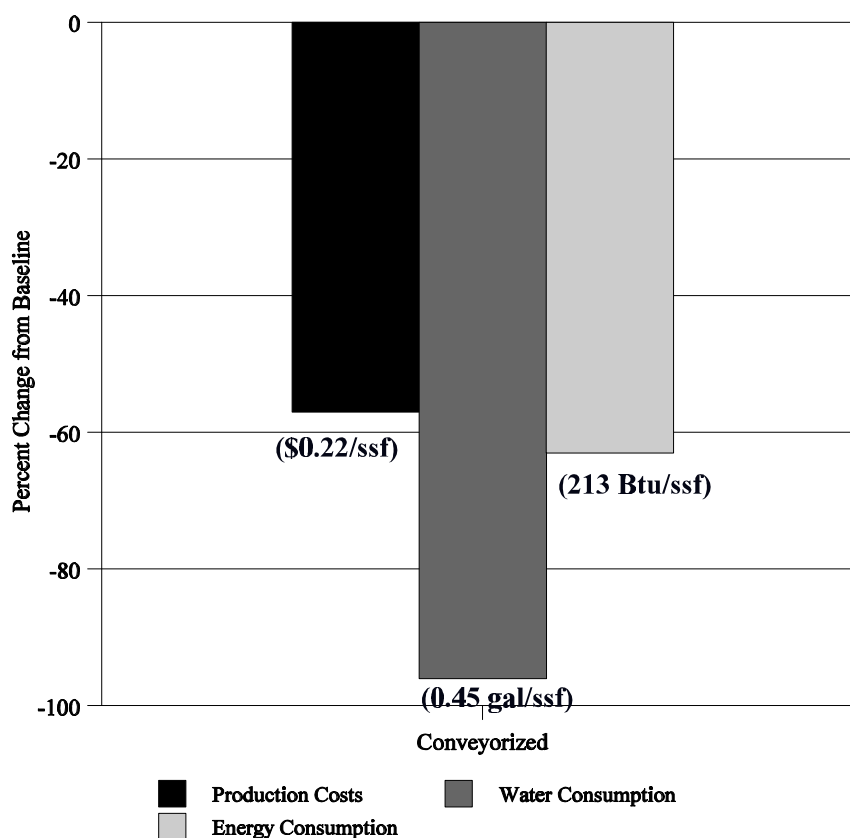
NE: Not Evaluated; due to lack of toxicity measure.

NR: Not Reported.

Social Benefits and Costs

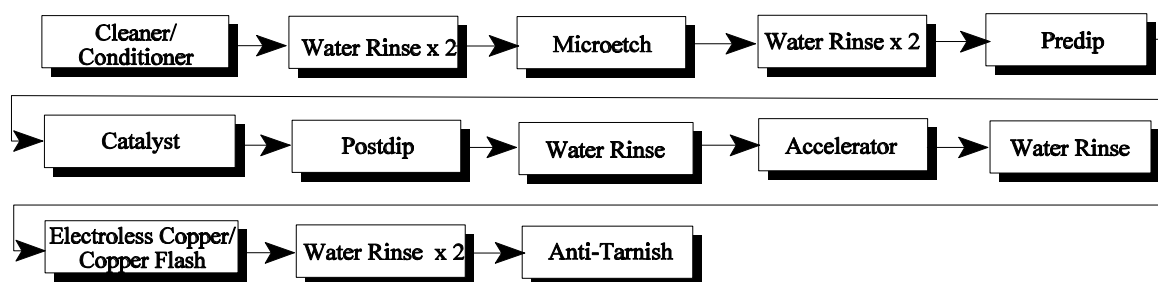
A qualitative assessment of the private and external benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the carbon technology from the baseline. Among other factors, this is due to lower occupational risks to workers and to reduced consumption of limited resources (water and energy).

Figure 7.4 Production Costs and Resource Consumption of Graphite Technology
(Percent Change from Baseline with Actual Values in Parentheses)



7.3.5 Non-Formaldehyde Electroless Copper Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Non-conveyorized.

Risk Characterization

Table 7.22 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the non-formaldehyde electroless copper technology. The risk characterization identified occupational inhalation risk concerns for one chemical and dermal risk concerns for two chemicals. No public health risk concerns were identified for the pathways evaluated. However, proprietary chemicals are not included in this assessment and toxicity values were not available for some chemicals.

Table 7.22 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Non-Formaldehyde Electroless Copper Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b				Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation		Dermal			
	Toxicity ^c (mg/m ³)	Risk Concerns	Toxicity ^c (mg/kg-d)	Risk Concerns		
Copper Sulfate	ND	NE	ND	NE	none	0.00002
Hydrochloric Acid	0.007 (RfC)	NA	ND ^d	NE	IARC Group 3	0.1
Hydrogen Peroxide	79	no	630 (NOAEL)	no	IARC Group 3	1.2
Isopropyl Alcohol; or 2-Propanol	980 (NOAEL)	no	100 (NOAEL)	no	none	9.0
Potassium Hydroxide	7.1	no	ND	NE	none	0.08
Potassium Persulfate	ND	NE	ND	NE	none	0.92
Sodium Chlorite	ND	NA	10 (NOAEL)	yes	none	0.00016
Sodium Hydroxide	2 (LOAEL)	no	ND	ND	none	2.5
Stannous Chloride	ND	NA	0.62 (RfD)	yes	none	0.0009
Sulfuric Acid	0.066 (NOAEL)	yes	ND ^d	NE	none	2.0

^a Only one non-formaldehyde electroless copper technology was evaluated. All chemicals listed were present in that product line.

^b Risk evaluated for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be low. Risk concerns are for line operator (the most exposed individual).

^c Toxicity measure is RfC, RfD, NOAEL, or LOAEL, as indicated. If not indicated, the type of toxicity measure was not specified in the available information, but assumed to be a LOAEL in risk calculations.

^d Chronic toxicity data are not typically available for strong acids.

ND: No Data. No toxicity measure developed for this pathway.

NE: Not Evaluated; due to lack of toxicity measure.

NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1×10^{-3} torr) and is not used in any air-sparged bath.

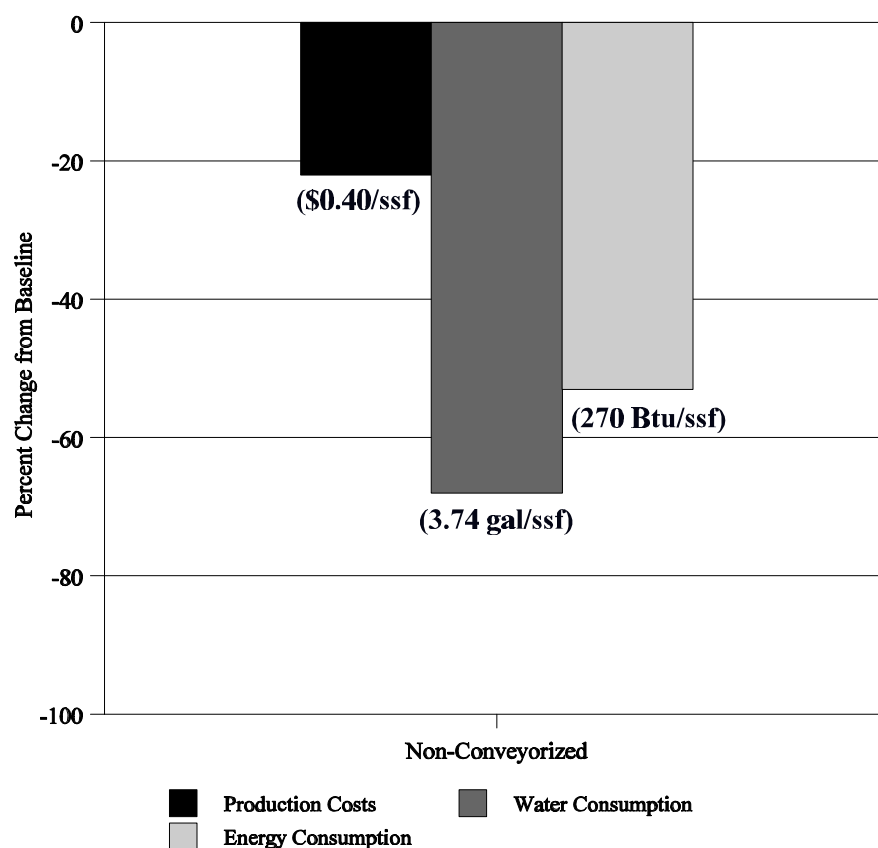
Performance

The performance of the non-formaldehyde electroless copper technology was demonstrated at two test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional costs (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. The non-conveyorized non-formaldehyde electroless copper process consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized electroless copper). Figure 7.5 lists the results of these analyses and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by 22 percent, 68 percent, and 53 percent, respectively.

Figure 7.5 Production Costs and Resource Consumption of Non-Formaldehyde Electroless Copper Technology
(Percent Change from Baseline with Actual Values in Parentheses)



Regulatory Concerns

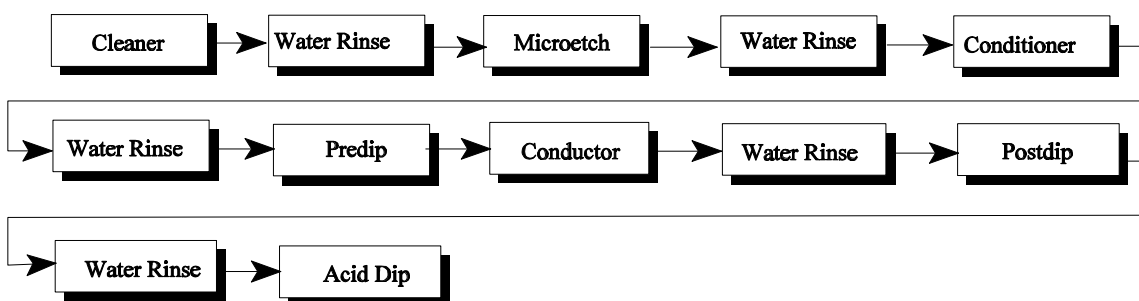
Chemicals contained in the non-formaldehyde electroless copper technology are regulated by the Clean Water Act, the Safe Drinking Water Act, the Clean air Act, the Superfund Amendments and Reauthorization Act, the Emergency Planning and Community Right-to-Know Act, and the Toxic Substances Control Act. The technology does not generate wastes listed as hazardous (P or U waste) under RCRA, but some wastes may have RCRA hazardous characteristics.

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the non-formaldehyde electroless copper technology from the baseline. Among other factors, this is due to lower occupational risks to workers and to reduced consumption of limited resources (water and energy).

7.3.6 Organic-Palladium Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Non-conveyorized and conveyorized.

Risk Characterization

Table 7.23 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the organic-palladium technology. The risk characterization identified occupational dermal risk concerns for one chemical, palladium salt. No occupational inhalation risk concerns were identified. The risk characterization identified public health risk concerns for the pathways evaluated. However, proprietary chemicals are not included in this table and toxicity data were not available for some chemicals.

Table 7.23 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Organic-Palladium Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b				Carcinogenicity Weight-of-Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c		Dermal ^d			
	Toxicity ^e (mg/m ³)	Risk Concerns	Toxicity ^e (mg/kg-d)	Risk Concerns		
Hydrochloric Acid	0.007 (RfC)	NA	ND ^f	NE	IARC Group 3	0.1
Palladium Salt	ND	NA	NR ^g	yes	none	NR
Sodium Bisulfate	ND	NA	ND ^h	NE	none	0.058
Sodium Carbonate	10 (NOAEL)	NA	ND	NE	none	2.4
Sodium Bicarbonate	10 (NOAEL) ⁱ	NA	ND	NE	none	2.4 ⁱ
Sodium Hypophosphite	ND	NA	ND	NE	none	0.006
Sodium Persulfate	ND	NA	ND ^h	NE	none	0.065
Trisodium Citrate 5,5-Hydrate or Sodium Citrate	ND	NA	ND	NE	none	3.3

^a Only one organic-palladium technology was evaluated. All chemicals listed were present in that product line.

^b Risk concerns are for MHC line operators (the most exposed individual).

^c Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.

^d Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.

^e Toxicity measure is RfC, RfD, NOAEL, or LOAEL as indicated.

^f Chronic dermal toxicity data are not typically developed for strong acids.

^g Toxicity data are available but not reported in order to protect proprietary chemical identities.

^h Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.

ⁱ Chemical properties and toxicity measures for sodium carbonate used in exposure assessment and risk characterization since these compounds form the same ions in water and are used in aqueous baths.

ND: No Data. No toxicity measure available for this pathway.

NE: Not Evaluated; due to lack of toxicity measure.

NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1×10^{-3} torr) and is not used in any air-sparged bath.

NR: Not Reported.

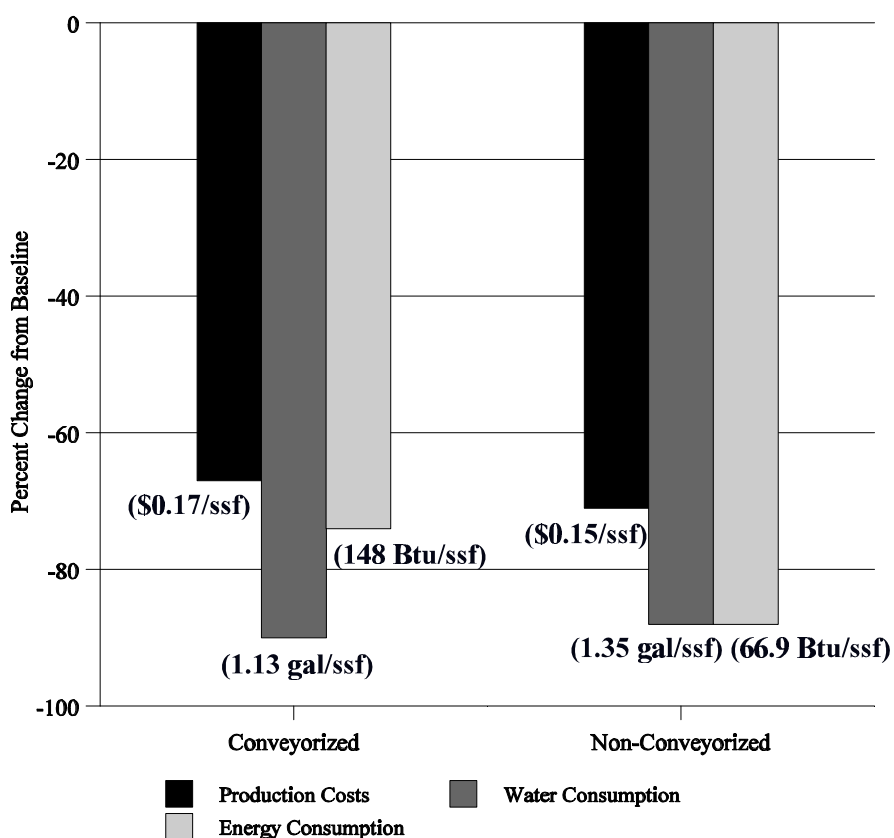
Performance

For the purposes of the Performance Demonstration project, the organic-palladium and tin-palladium technologies were grouped together into a single palladium technology category. The performance of the palladium technology was demonstrated at ten test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. With either equipment configuration, the organic-palladium technology consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized electroless copper). In addition, the conveyorized organic-palladium process consumed less water than the non-conveyorized process (\$1.13 gal/ssf vs. \$1.35 gal/ssf, respectively), but consumed more energy (148 Btu/ssf vs. 66.9 Btu/ssf). However, the conveyorized organic-palladium is not as cost effective as the non-conveyorized process (\$0.17/ssf vs. \$0.15/ssf, respectively). Figure 7.6 lists the results of these analyses and illustrates the percent changes in costs and resource consumption for either equipment configuration from the baseline.

Figure 7.6 Production Costs and Resource Consumption of Organic-Palladium Technology
(Percent Change from Baseline with Actual Values in Parentheses)



Regulatory Concerns

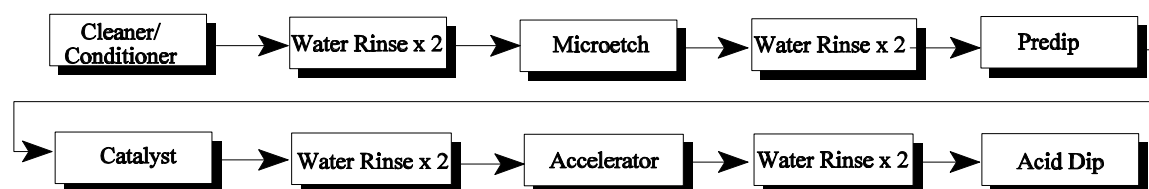
Chemicals contained in the organic-palladium technology are regulated by the Clean Water Act, the Clean Air Act, and the Emergency Planning and Community Right-to-Know Act. The technology does not generate wastes listed as hazardous (P or U waste) under RCRA, but some wastes may have RCRA hazardous characteristics.

Social Benefits and Costs

A qualitative assessment of the private and external (e.g., social) benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the organic-palladium technology from the baseline. Among other factors, this is due to lower occupational risks to workers and to reduced consumption of limited resources (water and energy).

7.3.7 Tin-Palladium Technology

Generic Process Steps and Typical Bath Sequence



Equip

ment Configurations Evaluated: Non-conveyorized and conveyorized.

Risk Characterization

Table 7.24 summarizes human and environmental hazards and risk concerns for non-proprietary chemicals in the tin-palladium technology. The risk characterization identified occupational inhalation risk concerns for two chemicals and dermal risk concerns for five chemicals. No public health risk concerns were identified for the pathways evaluated. However, five proprietary chemicals are not included in this table and toxicity values were not available for some chemicals. At least two of these chemicals (potassium carbonate and sodium bisulfate) have very low skin absorption, indicating risk from dermal exposure is not expected to be of concern.

Performance

For the purposes of the Performance Demonstration project, the organic-palladium and tin-palladium technologies were grouped together into a single palladium technology category. The performance of the palladium technology was demonstrated at ten test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to electroless copper.

Table 7.24 Summary of Human Health and Environmental Hazard Data and Risk Concerns for the Tin-Palladium Technology

Chemical ^a	Human Health Hazard and Occupational Risks ^b				Carcinogenicity Weight-of Evidence Classification	Aquatic Toxicity CC (mg/l)
	Inhalation ^c		Dermal ^d			
	Toxicity ^e (mg/m ³)	Risk Concerns	Toxicity ^e (mg/kg-d)	Risk Concerns		
1,3-Benzenediol	ND	NA	100 (NOAEL)	no	IARC Group 3	0.0025
Copper (I) Chloride^f	0.6 (LOAEL)	no	0.07 (LOAEL)	yes	EPA Class D	0.0004
Copper Sulfate^f	ND	NE	ND	NE	none	0.00002
Dimethylaminoborane	ND	NA	ND	NE	none	0.007 ^g
Ethanolamine	12.7 (LOAEL)	yes	320 (NOAEL)	no	none	0.075
Fluoroboric Acid	ND	NE	0.77	yes	none	0.125
Hydrochloric Acid^h	0.007 (RfC)	NA	ND	NE ⁱ	IARC Group 3	0.1
Hydrogen Peroxide	79	no	630 (NOAEL)	no	IARC Group 3	1.2
Isopropyl Alcohol; or 2-Propanol	980 (NOAEL)	no	100 (NOAEL)	no	none	9.0
Lithium Hydroxide	ND	NA	ND	NE	none	ND
Palladium^j	ND	NA	0.95 (LOAEL)	yes	none	0.00014
Palladium Chloride^j	ND	NA	0.95 (LOAEL)	yes	none	0.00014
Phosphoric Acid	ND	NE	ND	ND	none	0.138
Potassium Carbonate	ND	NA	ND ^k	NE ^l	none	>3.0
Sodium Bisulfate	ND	NA	ND ^k	NE	none	0.058
Sodium Chloride	ND	NA	ND	NE ^l	none	2.8
Sodium Hydroxide	2 (LOAEL)	NA	ND	NE	none	2.5
Sodium Persulfate	ND	NE	ND	NE ^l	none	0.065
Stannous Chloride^m	ND	NA	0.62 (RfD)	yes	none	0.0009
Sulfuric Acid^h	0.066 (NOAEL)	yes	ND	NE ^l	none	2.0
Triethanolamine	ND	NA	32 (LOAEL)	no	none	0.18
Vanillin	ND	NE	64 (LOAEL)	no	none	0.057

^a Chemicals in bold were in all tin-palladium technologies evaluated, unless otherwise noted.

^b Risk concerns are for MHC line operators (the most exposed individual).

^c Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.

^d Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.

^e Toxicity measure is RfC, RfD, NOAEL, or LOAEL as indicated. If not indicated, the type of toxicity measure was not specified in the available information, but assumed to be a LOAEL in risk calculations.

^f Either copper (I) chloride or copper sulfate was listed on the MSDSs for four of five tin-palladium lines evaluated.

^g Estimated by EPA's Structure-Activity Team.

^h Hydrochloric and sulfuric acid were listed on the MSDSs for four of five tin-palladium lines evaluated.

ⁱ Chronic dermal toxicity data are not typically developed for strong acids.

^j Palladium or palladium chloride was listed on the MSDSs for three of five tin-palladium lines evaluated. The MSDSs for the two other lines did not list a source of palladium.

^k Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.

¹ Dermal exposure level for line operator of conveyORIZED equipment was in top ten percent of dermal exposures for all MHC chemicals.

^m Stannous chloride was listed on the MSDSs for four of the five tin-palladium lines evaluated. The MSDSs for the remaining tin-palladium product line did not list a source of tin.

ND: No Data. No toxicity measure available for this pathway.

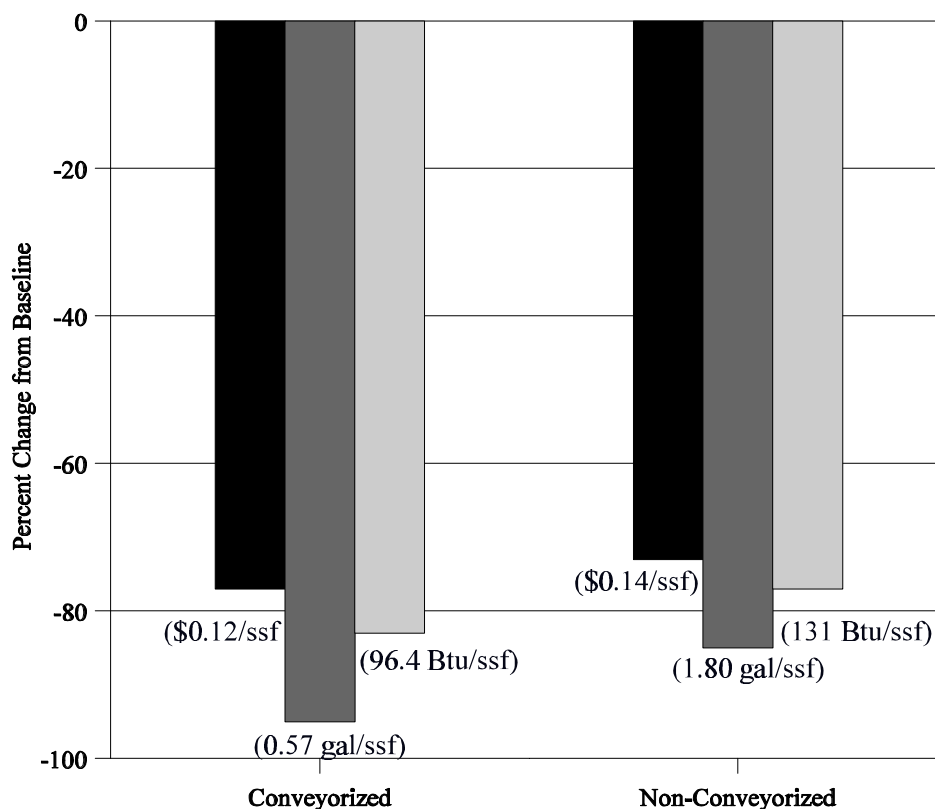
NE: Not Evaluated; due to lack of toxicity measure.

NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1×10^{-3} torr) and is not used in any air-sparged bath.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 350,000 ssf and the amount of resources (water and energy) consumed. This information was used with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf. With either equipment configuration, the tin-palladium technology consumed less water and energy and was more cost-effective than the baseline process (non-conveyORIZED electroless copper). In addition, the conveyORIZED tin-palladium process consumed less water and energy and was more cost-effective than the non-conveyORIZED process (\$0.12/ssf vs. \$0.14/ssf, respectively). Figure 7.7 lists the results of these analyses and illustrates the percent changes in costs and resource consumption for either equipment configuration from the baseline.

Figure 7.7 Production Costs and Resource Consumption of Tin-Palladium Technology
(Percent Change from Baseline with Actual Values in Parentheses)



Regulatory Concerns

Production Costs
 Water Consumption
 Energy Consumption

7.3 TECHNOLOGY SUMMARY PROFILES

Chemicals contained in the tin-palladium technology are regulated by the Clean Water Act, the Safe Drinking Water Act, the Clean Air Act, the Superfund Amendments and Reauthorization Act, the Emergency Planning and Community Right-to-Know Act, and the Toxic Substances Control Act. In addition, the technology generates a waste listed as hazardous (U waste) under RCRA.

Social Benefits and Costs

A qualitative assessment of the private and external (e.g., social) benefits and costs of this technology suggests there would be net benefits to society if PWB manufacturers switched to the tin-palladium technology from the baseline. However, this alternative contains chemicals of concern for occupational inhalation risk (for non-conveyorized equipment configurations) and occupational dermal contact risks (for either equipment configuration). Among other factors, net social benefits would be due primarily to lower production costs and to reduced consumption of limited resources (water and energy).

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